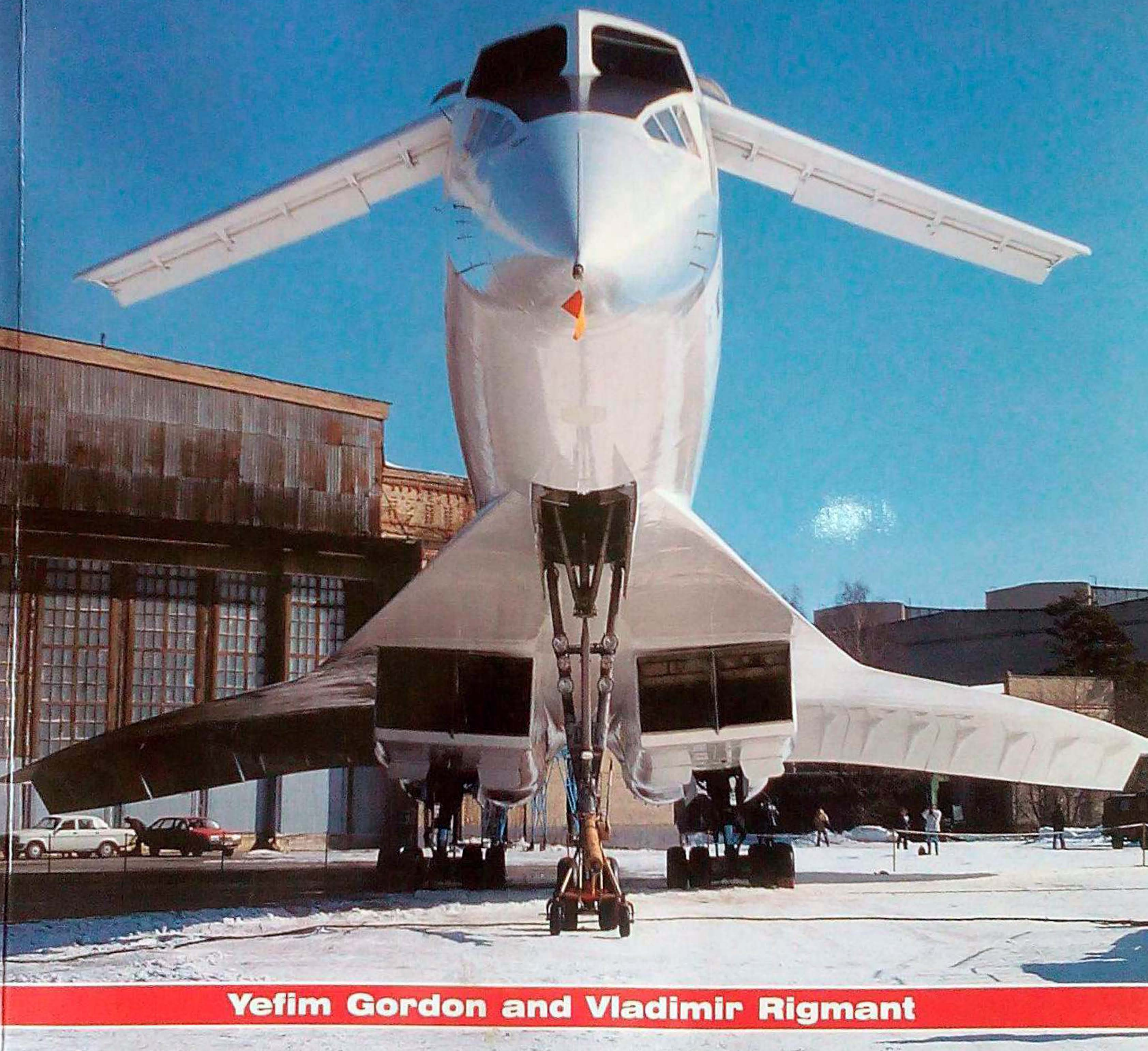
RED STAR VOLUME 24

Tupolev Tu-144

Russia's Concorde



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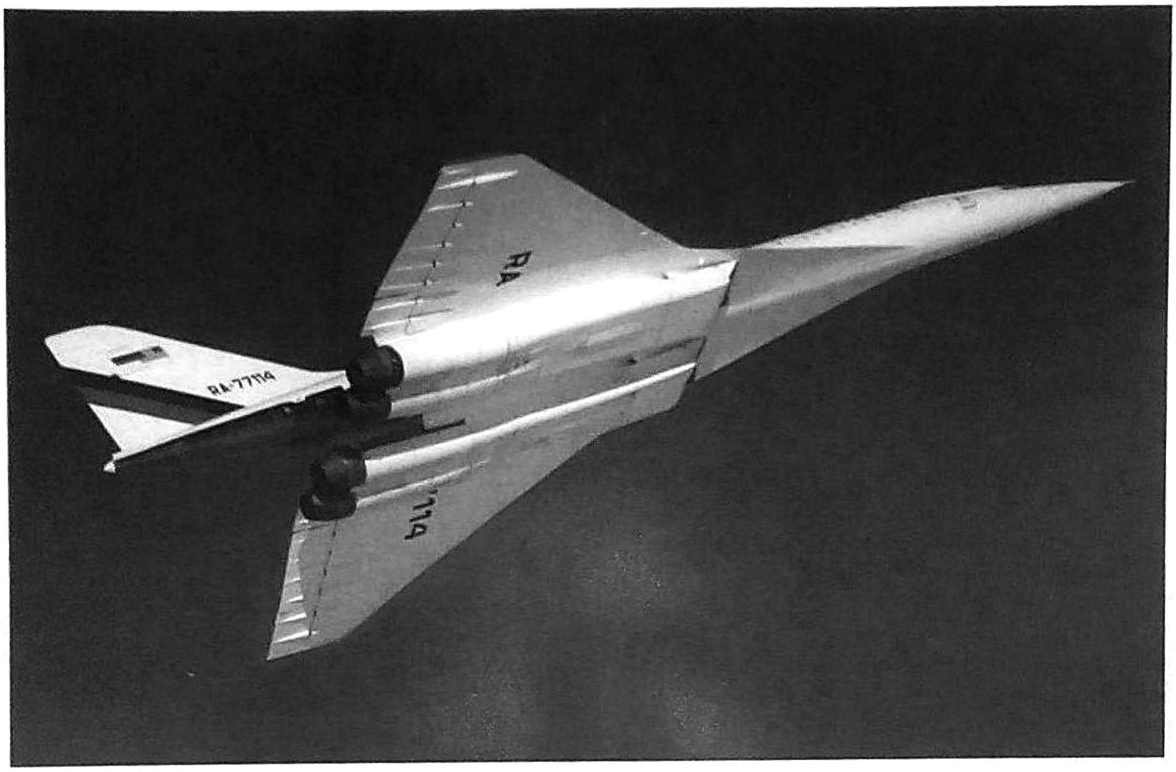

Yefim Gordon and Vladimir Rigmant

Original translation by Dmitriy Komissarov

MIDLAND
An imprint of
Ian Allan Publishing

Tupolev Tu-144: Aeroflot's Supersonic Dream

ISBN(10) 1 85780 216 0
ISBN(13) 978 1 85780 216 0
Published by Midland Publishing
4 Watling Drive, Hinckley, LE10 3EY, England
Tel: 01455 254 490 Fax: 01455 254 495
E-mail midlandbooks@compuserve.com

Midland Publishing is an imprint of
Ian Allan Publishing Ltd

Worldwide distribution (except North America)
Midland Counties Publications
4 Watling Drive, Hinckley, LE10 3EY, England
Telephone: 01455 254 450 Fax: 01455 233 737
E-mail midlandbooks@compuserve.com
www.midlandcountiessuperstore.com

North American trade distribution:
Specialty Press Publishers & Wholesalers Inc.
39966 Grand Avenue, North Branch, MN 55056, USA
Tel: 651 277 1400 Fax: 651 277 1203
Toll free telephone: 800 895 4585
www.specialtypress.com

Design concept and layout by
Polygon Press Ltd (Moscow,Russia)

Line drawings by Andrey Yurgenson

This book is illustrated with photographs by Yefim Gordon, ITAR-TASS, as well as from the archives of the Tupolev PLC, Yefim Gordon, Sergey and Dmitriy Komissarov, and the Russian Aviation Research Trust

Printed in England by
Ian Allan Printing Ltd
Riverdene Business Park, Molesey Road,
Hersham, Surrey, KT12 4RG

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Front cover: The Tu-144LL at Zhukovskiy during its roll-out ceremony.
Rear cover, top: Tu-144D CCCP-77115 stored at Zhukovskiy; bottom: one more view of Tu-144LL RA-77114.

Introduction

The advent of turbojet engines revolutionised first and foremost military aviation. The first attempts to adapt the new powerplant to combat aircraft were undertaken in the late 1930s, and the first viable jet fighters and bombers appeared in time to see action in the Second World War. In the immediate post-war years, aircraft designers in the world's leading aircraft manufacturing countries could turn their attention to the task of introducing jet propulsion in commercial aviation as well. This took air travel to hitherto unimaginable levels of comfort and speed. Work on jet airliners went ahead both in the Soviet Union and in the West.

It should be noted that in spite of the work on jet engines undertaken in the Soviet Union, the country – unlike Germany, Great Britain and the USA – was not in a position to test and field any actual combat jets during the war; the first indigenous jet aircraft took to the air in 1946. However, the Soviet designers learned fast and did their best to catch up with their Western colleagues, as both British and American companies already had passenger jets on the drawing boards; the 44-seat, four-turbojet de Havilland DH.106 Comet 1 first flew on 27th July 1949 and commenced scheduled services on 2nd May 1952.

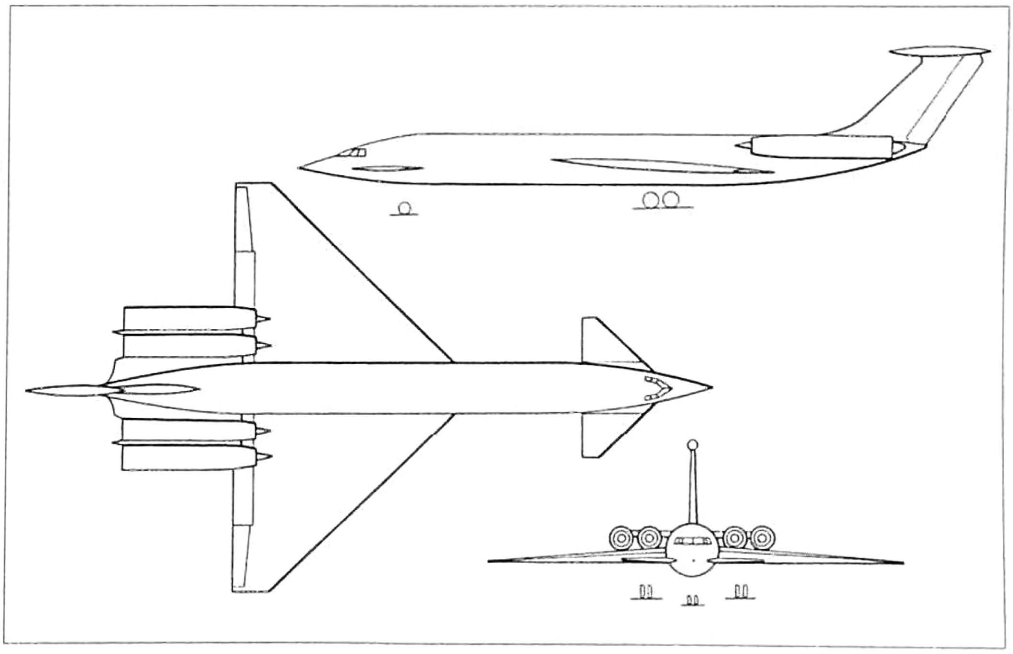
The creation of an indigenous jet airliner was not only as a means of reducing the time needed to take passengers from A to B – important though this objective was, given the Soviet Union's vast territory and underdeveloped surface transport network – but also as a matter of national prestige. This politically important task was entrusted to the nation's leading designer of commercial aircraft – the OKB-156 design bureau led by Andrey Nikolayevich Tupolev, the doyen of Soviet heavy aircraft construction. (OKB = *opytno-konstrooktorskoye byuro* – experimental design bureau; the number is a code allocated for security reasons. In 1991 OKB-156 became the Tupolev Aviation Scientific & Technical Complex (ANTK imeni Tupoleva – *aviatsionnyy naoochno-tekhnicheskiy kompleks*), often referred to as ANTK Tupolev in the West; today the company is known as the Tupolev Public Limited Company (OAO Tupolev – *otkrytoye aktsionehrnoye obshchestvo*).

The first Soviet commercial jet was designated Tu-104. To save time Andrey N. Tupolev opted for maximum structural and systems commonality with the Tu-16 twinjet medium bomber. Though not the world's first jet airliner to fly (the maiden flight took place on 17th June 1955) and carry fare-paying passengers, the Tu-104 took Aeroflot, the sole Soviet airline, into the jet age and became the world's first jet airliner in sustained commercial service following the withdrawal of the Comet 1 after a series of fatal accidents.

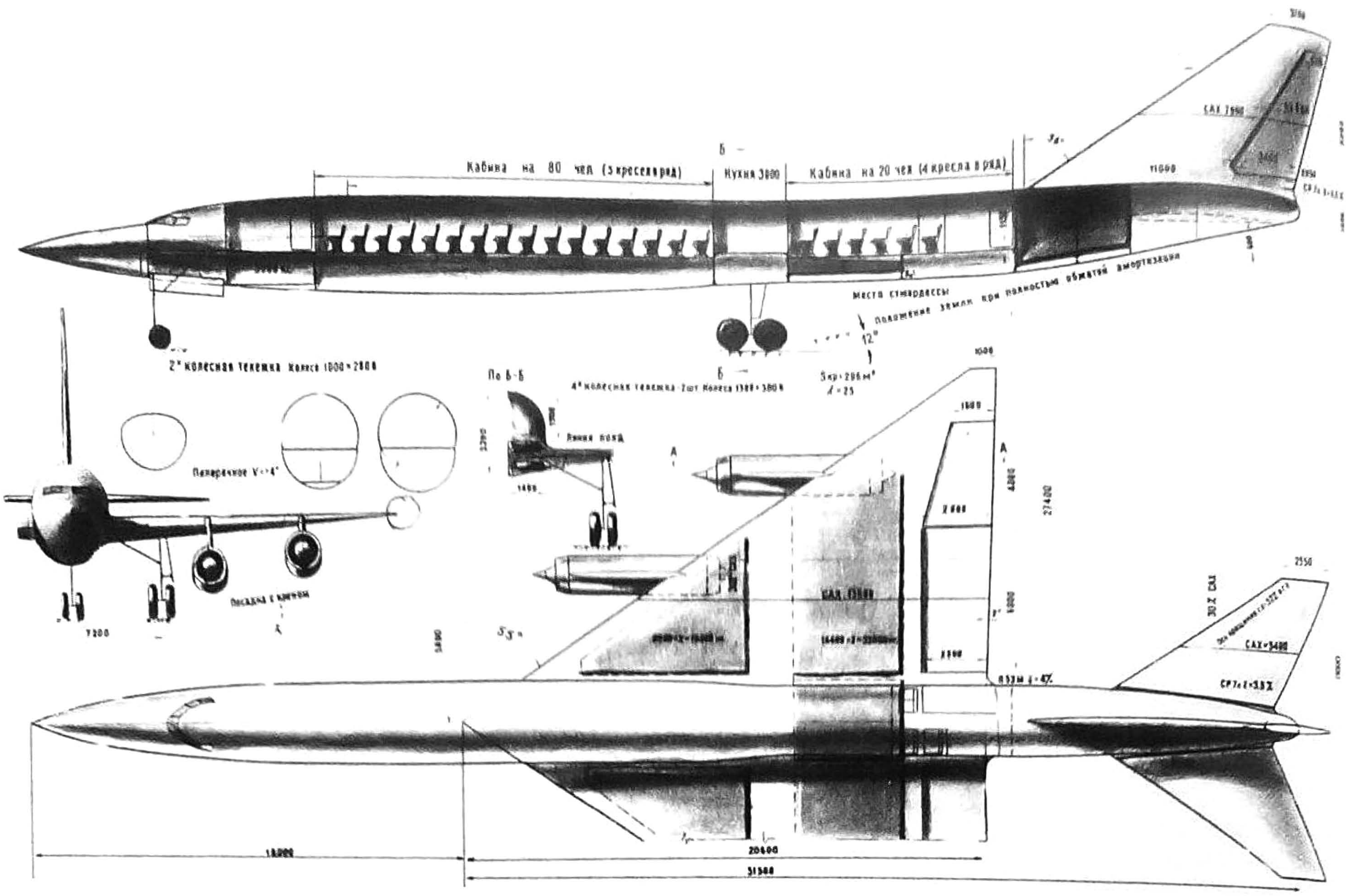
Several years later the original scenario was repeated. As aviation technology developed and aircraft approached – and eventually exceeded – the speed of sound, military aviation was the first to benefit from this progress. Then, after supersonic fighters and bombers had become a reality in the late 1950s, aircraft designers on both sides of the Iron Curtain almost immediately began preparing projects of supersonic airliners – or, to use a term coined shortly thereafter, supersonic transports (SSTs). As might be imagined, the first of these projects were based on supersonic bombers. The early SST projects developed in the Soviet Union deserve a brief description.

The OKB-240 design bureau headed by Sergey Vladimirovich Il'yushin made its only known foray into supersonic airliner design in 1959 at the initiative of its leader. Designated IL-66, the projected SST had a canard (tail-first) configuration with large low-set cropped-delta wings and low-set all-moving cropped-delta foreplanes; the sharply-swept tail terminated in a large cigar-shaped fairing. The twin-wheel nose landing gear unit retracted forward and the four-wheel main gear bogies inward into the fuselage. Four turbojets having axisymmetrical air intakes with shock cones were mounted in pairs on the aft fuselage sides, echoing the layout of the IL-62 subsonic airliner. Il'yushin expected engines of the required thrust class to be available: at that time the engine design bureaux led by Vladimir Yakovlevich Klimov (OKB-117) and Sergey Konstantinovich Tumanskiy (OKB-300) were hard at work on afterburning turbojets (the VK-15B and the R15-300 respectively) which could prove suitable for the IL-66. The VK-15B had a take-off rating of 15,600 kgp (34,400 lbst), and the R15-300 was rated at 11,200-13,500 kgp (24,700-29,770 lbst).

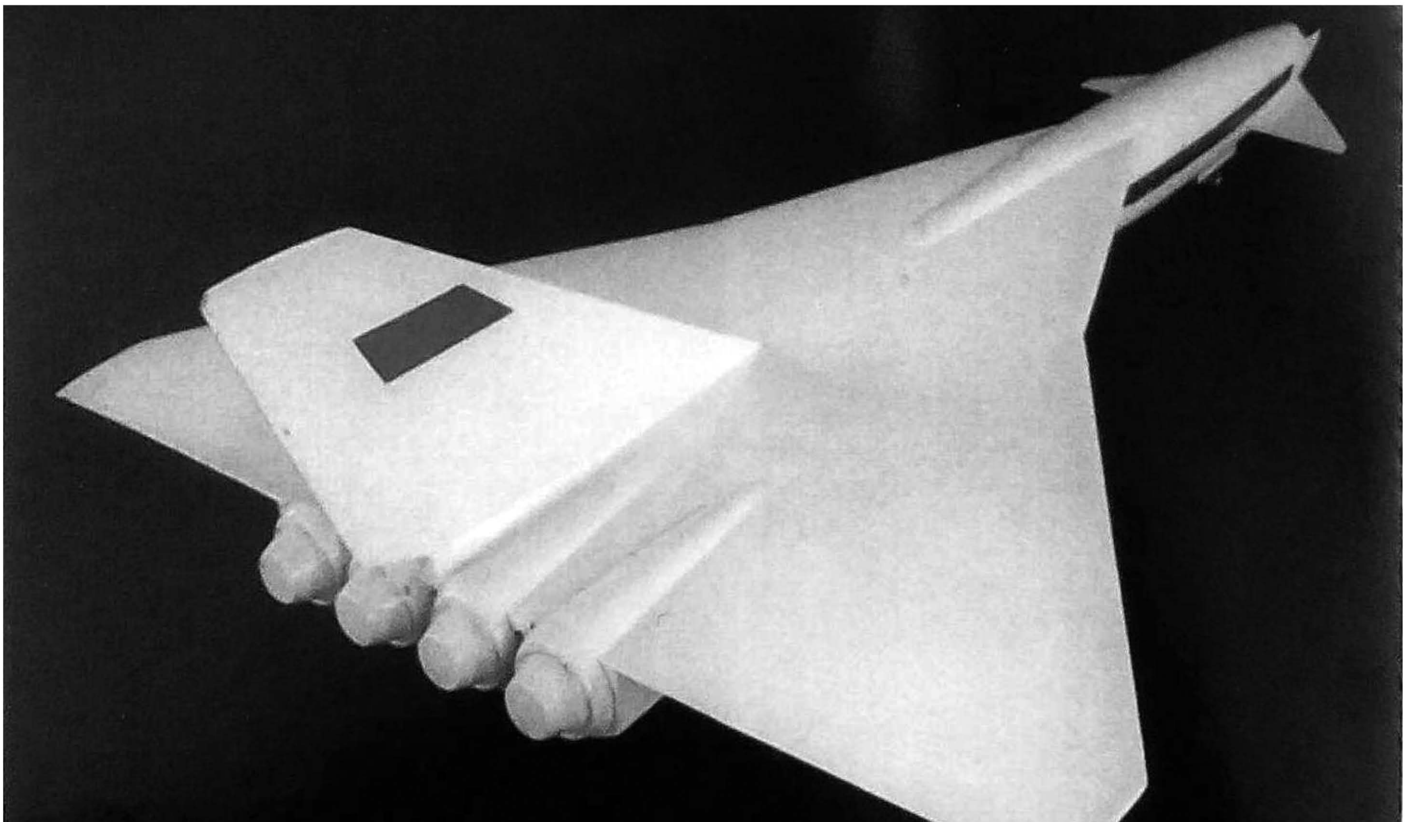
According to preliminary design studies the IL-66 was expected to carry 60-100 passengers to distances of up to 7,300 km (4,537 miles) at a cruising speed of 3,000 km/h (1,865 mph). The aircraft could be used on long-haul routes, such as the Moscow-



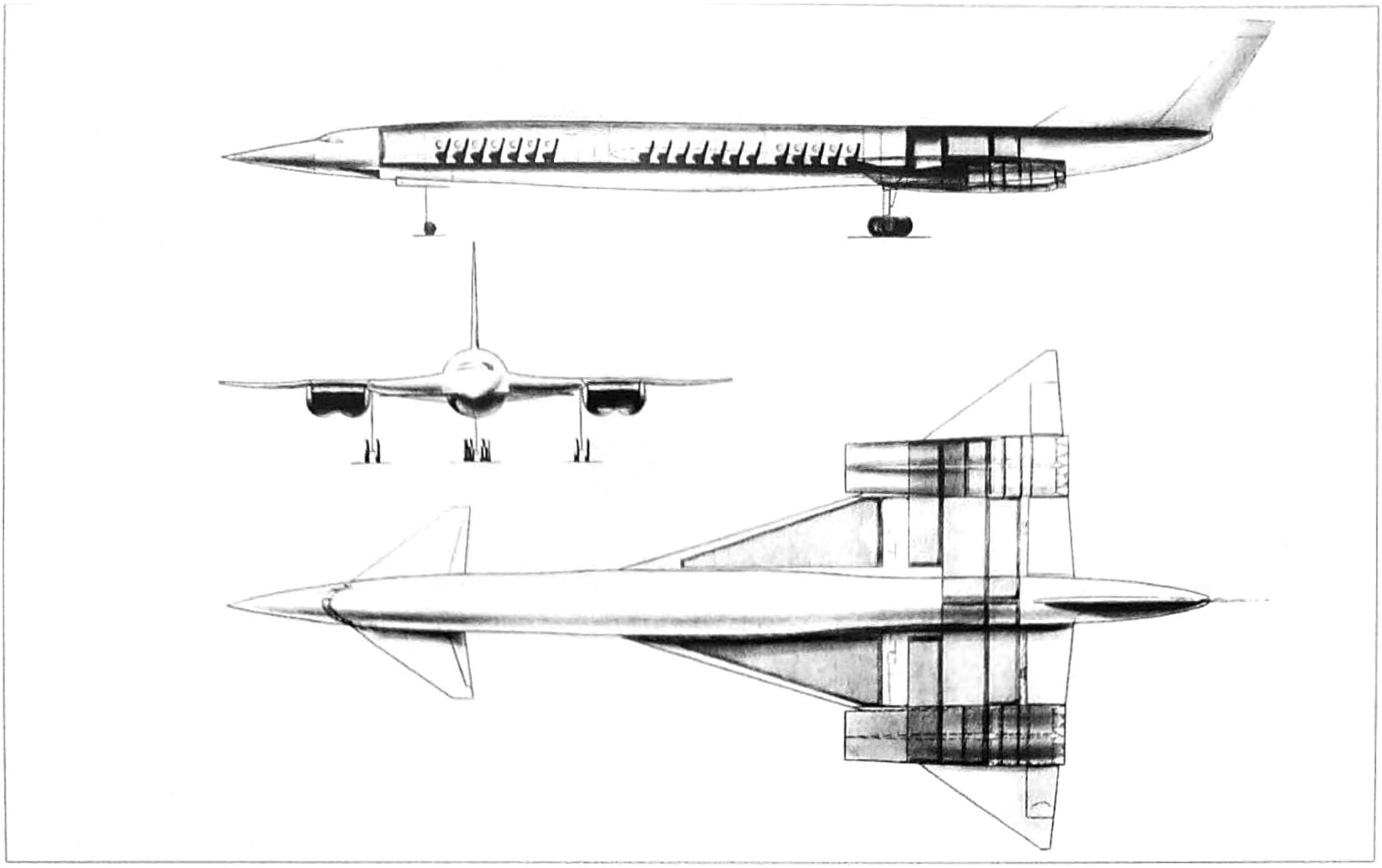
A three-view of the projected Il'yushin IL-66 supersonic airliner.



Above: One of the Myasishchev M-53's many project configurations featuring simple delta wings, conventional tail surfaces and spaced engine nacelles. The front view shows the alternative wingtip placement of the outer engines. The forward cabin seats 80 passengers five-abreast; the rear one seats 20 four-abreast.



This model illustrates the final configuration of the M-53 with high-set cranked-delta wings, canards and the engines located all together.



Another project configuration of the M-53 with a canard layout, paired engine nacelles and a bicycle undercarriage.

Khabarovsk service. In the designers' opinion, putting an SST into operation on that route would offer a considerable time saving for passengers and would be economically viable.

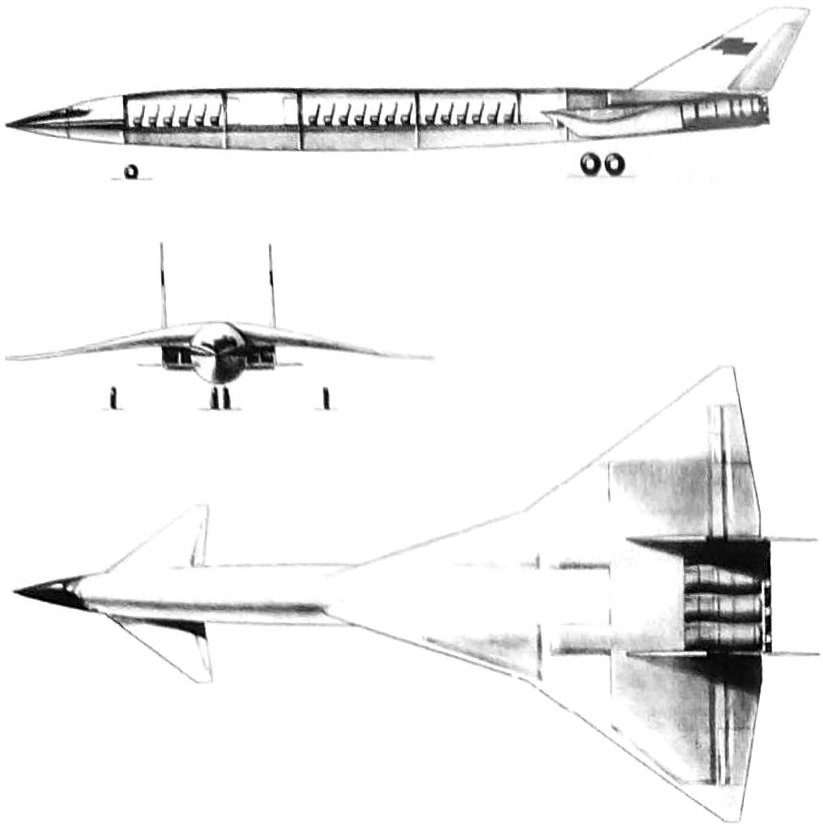
In the spring of 1960 Sergey V. Il'yushin approached the Soviet Council of Ministers (government) with a proposal that the IL-66 project be included in the prototype construction plan drawn up annually by the State Committee for Aviation Hardware (GKAT – *Gosoodarstvennyy komitet po aviatsionnoy tekhnike*). GKAT was the name by which the former Ministry of Aircraft Industry (MAP – *Ministerstvo aviatsionnoy promyshlennosti*) was known in from 1957 to 1965 before reverting to its original name and 'rank'. However, the Commitee's leaders took a justifiably sceptical view of the project which was obviously far too ambitious and clearly beyond the technological capacity of the Soviet aircraft industry at that time. Il'yushin was advised to study the feasibility of an airliner with a lower supersonic speed, featuring an airframe made of the usual aluminium alloys (the IL-66 project was based on the use of heat-resistant steel alloys).

Following these instructions, OKB-240 brought out a completely reworked project redesignated IL-72. Its design specifications were more realistic – the seating capacity was reduced to 40-60 passengers, the cruising speed target was Mach 2.2. Lower speed made it possible to choose aluminium alloys as construction materials. The range was expected to be 4,000-4,500 km (2,486-2,797 miles). On 14th February 1961 these design targets were discussed at the OKB's Technical council. However, the OKB was unable to proceed with this project, its resources being overtaxed by work on the IL-18 turboprop airliner, the IL-38 anti-submarine warfare aircraft and by the construction of the IL-62 prototype. No information is available on the layout of the IL-72.

Draft studies for an SST were also made by Vladimir Mikhaïlovich Myasishchev's OKB-23 which drew up several unusual SST projects. Designated M-53, the aircraft came in a variety of project configurations based on its strategic bombers/missile-carriers. One version shared the layout of the M-50/M-52 experimental bombers, featuring high-set cropped-delta wings with two engines on underwing pylons and two at the tips, conventional tail surfaces and a bicycle undercarriage. Another similar version called M-53A had four underwing engine nacelles and a tricycle undercarriage. Other versions derived from the unbuilt M-56/M-57 bombers were more radical, featuring a canard layout with cranked-delta wings and four underwing engines in spaced nacelles (M-53B) or paired lifting-body nacelles (M-53V). The most exotic variant was the M-53G using a canard layout with four engines located in a common nacelle so that the nozzles were located between the twin vertical tails (this necessitated the use of a bicycle undercarriage). Various engines were considered, including the Dobrynin VD-7K and the Zoobets RD-16-23 and M-16-17P.

The ultimate version of the M-53 powered by four 17,000-kgp (37,480-lbst) RD-16-23 engines was 51.3 m (168 ft $3\frac{11}{16}$ in) long, with a wingspan of 27 m (88 ft 7 in) and a height on ground of 10.8 m (35 ft $5\frac{13}{64}$ in). The aircraft was to have a take-off weight of 165 tons (363,760 lb) and a payload of 12 tons (26,455 lb), being flown by a crew of three and carrying 130 passengers. Range with maximum fuel was 6,000 km (3,726 miles), the cruising speed 2,200 km/h (1,366 mph) and the cruise altitude 16,000-17,000 m (52,490-55,770 ft). This version was submitted to GKAT for review on 29th August 1960, but the liquidation of the Myasishchev OKB by the Soviet government two months later brought all further work to an end.

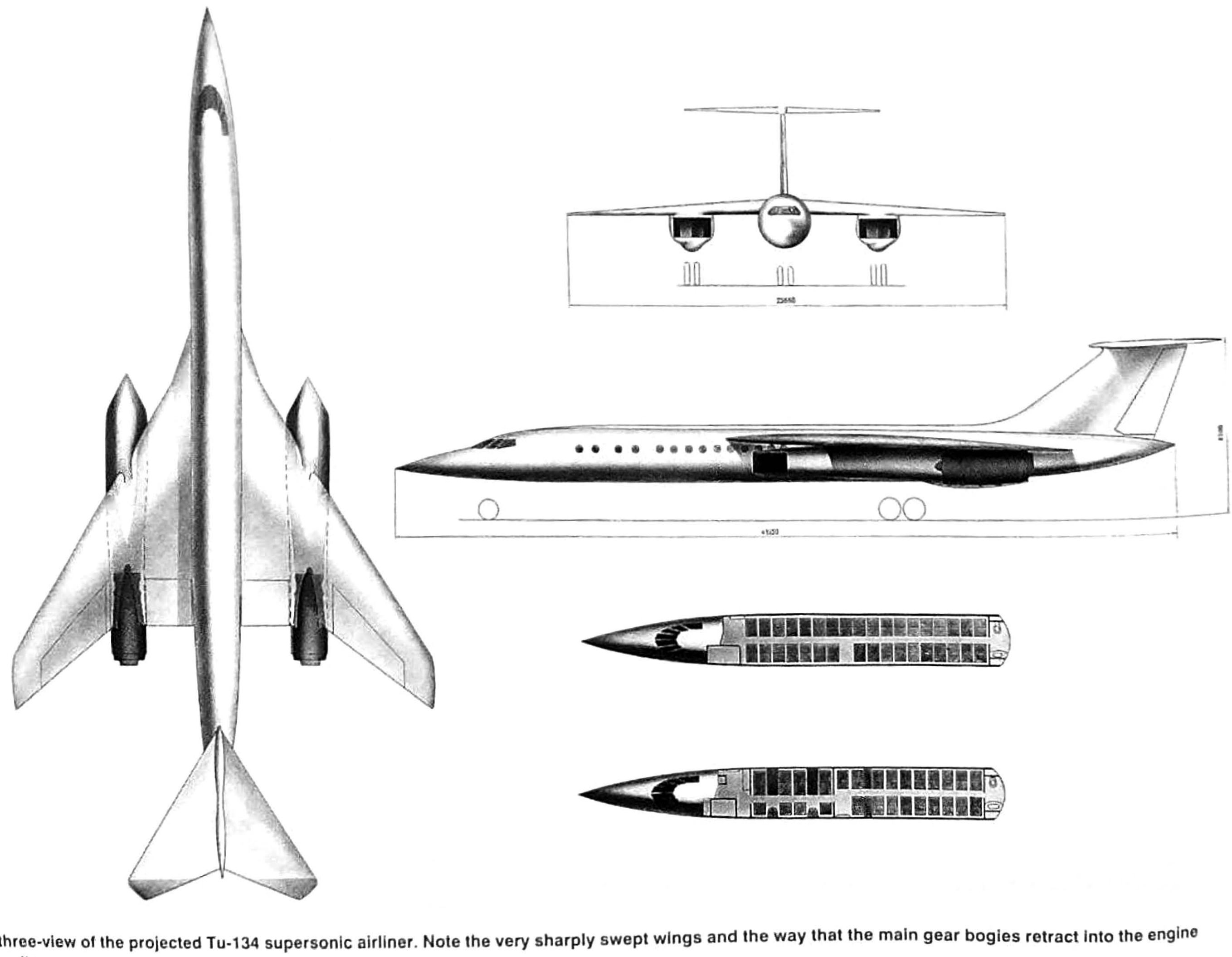
In the early 1960s the Tupolev OKB embarked on its first SST project, provisionally designated '134' (Tu-134, the first aircraft to bear the designation). In accordance with



Above: A three-view of the final M-53 configuration

the OKB's practice, the project was based on a bomber design – the stillborn '106A' – and became the responsibility of Sergey Mikhaïlovich Yeger's section. Four preliminary design (PD) projects were prepared (two with Kuznetsov NK-6 afterburning turbofans and two with Dobrynin VD-19R2 afterburning turbojets), differing in the wing and engine placement. The work proceeded no further work than the PD stage and the designation was re-used shortly afterwards for a well-known subsonic airliner

Two versions of the airframe were considered (with high-set and low-set wings), each with the alternative of two Kuznetsov NK-6 afterburning turbofans or four Dobrynin VD-19R2 afterburning turbojets. The low-wing version was 45.9 m (150 ft 7 in) long and 10.5 m (34 ft $5\frac{25}{64}$ in) tall, while the high-wing version was 42.15 m (138 ft $3\frac{29}{64}$ in) long and 9.3 m (30 ft $6\frac{9}{64}$ in) tall. Both versions had a wing span of 23.6 m (77 ft $5\frac{9}{64}$ in), a maximum payload of 8,000 kg (17,640 lb), a cruising speed of 2,100 km/h (1,304 mph) and a seating capacity of 50-70 passengers. Estimated range was 3,000-3,500 km (1,863-2,173 miles) at supersonic speed and 4,000-4,500 km (2,484-2,795 miles) at subsonic speed.



A three-view of the projected Tu-134 supersonic airliner. Note the very sharply swept wings and the way that the main gear bogies retract into the engine nacelles.

Chapter 1

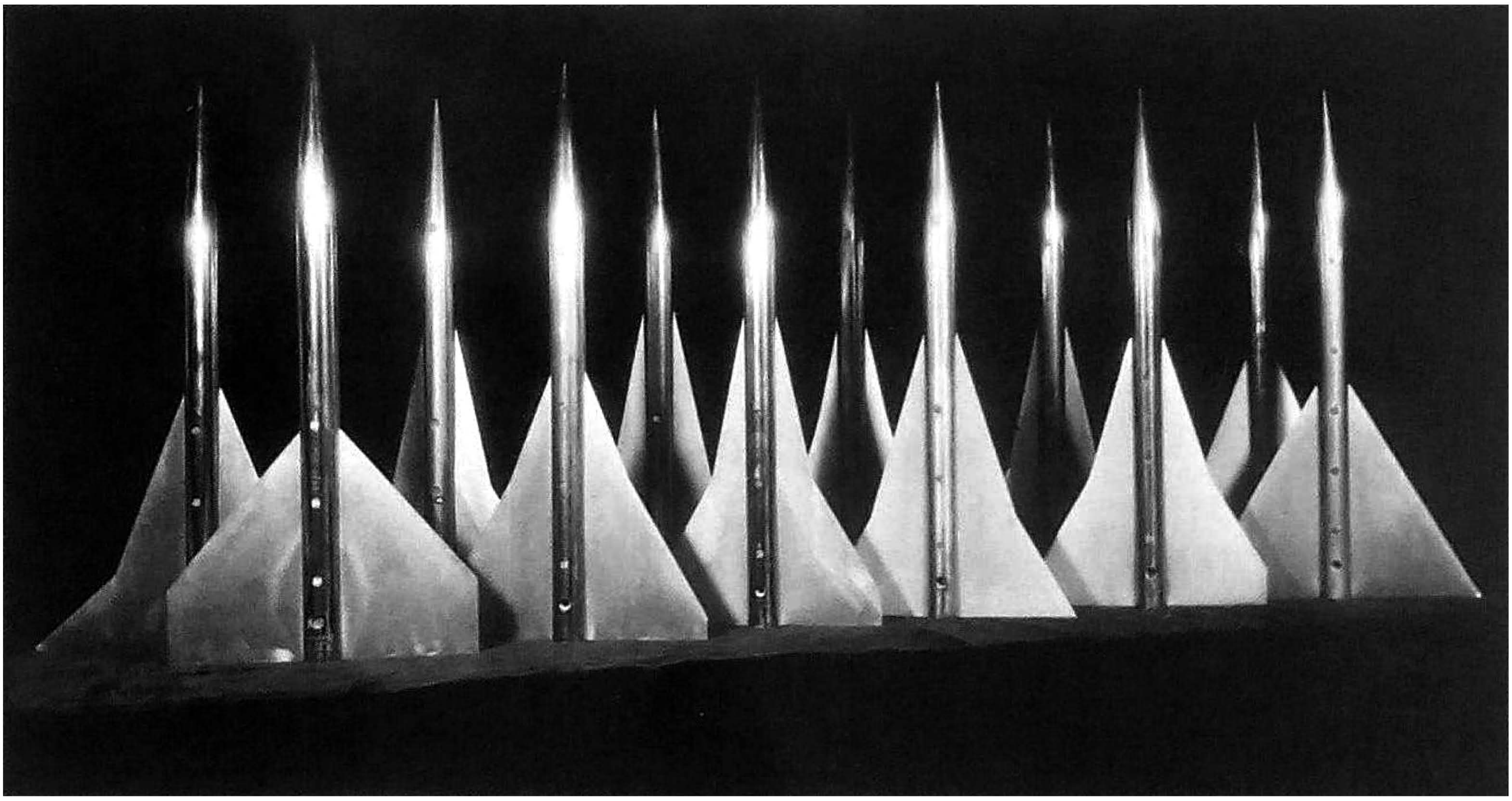
The Tu-144 is Born

The initial attempts to create a supersonic airliner by simply adapting the design of one of the first supersonic bombers – an approach tried successfully by the Tupolev OKB with its subsonic airliners of the 1950s – showed that this 'quick fix' approach did not work, or at least that it was extremely hard to achieve the desired result in this fashion. This was because the early heavy supersonic combat jets, which could in theory have served as the basis for an SST, were only intended for a brief supersonic dash over the target, with their airframes and systems designed accordingly, whereas a supersonic airliner had to be capable of sustained cruise at a speed of at least Mach 2.0.

Additionally, the character of airline operations with their more frequent flights as compared to a combat aircraft placed higher demands on the reliability of all of the airliner's structures and systems, especially considering the longer duration of supersonic cruise. Little by little, having analysed all options open to them, aircraft designers on both sides of the Iron Curtain became convinced that a supersonic airliner had to be a 'clean sheet of paper' design if it was to be economically efficient.

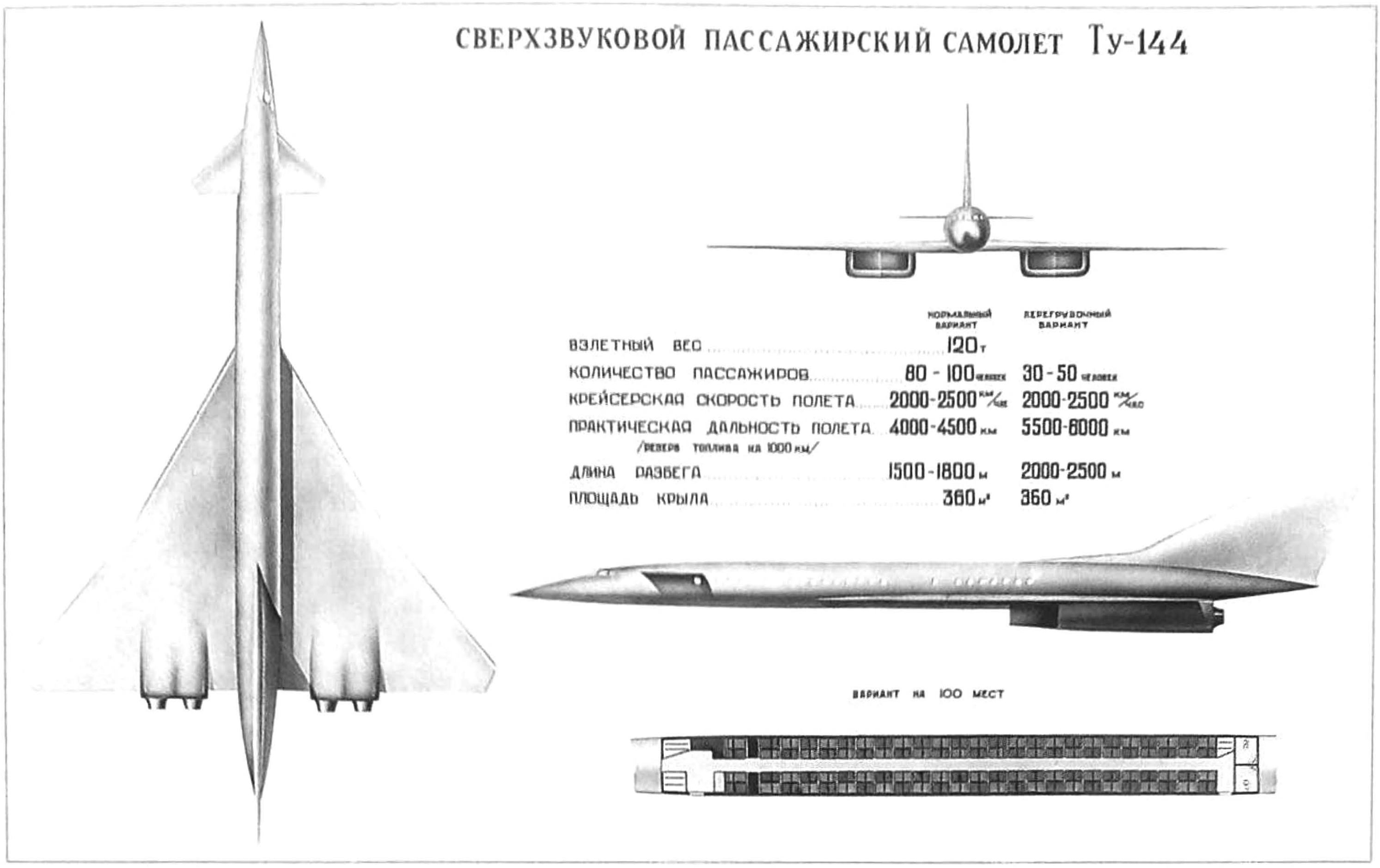
In the early 1960s the British Aircraft Corporation (BAC) and the French consortium Aérospatiale teamed up to begin practical design work on a supersonic airliner aptly named Concorde; the initial research on this project had begun in 1955-56. Cruising at Mach 2+, the Concorde was to carry 120-140 passengers over a distance of 6,000-6,500 km (3,730-4,040 miles). Concurrently, proceeding from their perspective of the world market for supersonic airliners, all of the major US transport aircraft manufacturers (Boeing, Lockheed and Douglas) started work on much larger SSTs designed to carry 250-300 passengers over 7,000-8,000 km (4,350-4,970 miles) with a cruising speed of up to Mach 3. Even making allowances for America's huge financial resources and technological potential, these were 'pie in the sky' projects which were thirty or even forty years ahead of their time; in fact, they were closer in their ideology to the later second-generation supersonic transport (SST-2) concept which, even now, is facing an uncertain future.

An assessment of the future SST's operating conditions made by Soviet experts (with due regard to the national aircraft industry's current technological level and its prospects for the near future, as well as to the capabilities of the Soviet economy and to Aeroflot's needs) showed that the best way to go for the Soviet designers was to develop an aircraft similar to the Anglo-French Concorde in its design performance. The Soviet aircraft industry's research establishments and manufacturing enterprises were now facing a whole range of scientific and technical challenges which neither subsonic commercial aviation nor supersonic military aviation had had to deal with before. First of all, the supersonic airliner's lift/drag ratio at Mach 2.0-2.2 needed to be improved radically in order to obtain the specified range of 6,500 km (4,040 miles) with 100-120 passengers in supersonic cruise. The target figure was 7.5-8.0 or better, which was much higher than the values hitherto achieved with Soviet supersonic



Looking rather like a collection of prizes, these very preliminary wind tunnel models illustrate some of the possible wing configurations explored during the Tu-144's preliminary design stage.

Above and below: This model depicts one of the Tu-144's earliest project configurations based on the unbuilt Tu-135 bomber, retaining the latter aircraft's canard layout, wings and engine nacelles. What look like eight-wheel main gear bogies are actually pairs of struts with four-wheel bogies in tandem.



A three-view of a similar project configuration featuring shoulder-mounted, not low-set, canards and clipped wingtips. The figures in the centre denote the take-off weight, seating capacity, cruising speed, effective range, take-off run and wing area for the normal (left) and high gross weight configurations.

bombers and missile strike aircraft in the same flight conditions. By comparison, the calculated values at Mach 2.0 were 4.4 for the Tu-22 bomber, 5.5 for the Myasishchev M-50 bomber, 5.6 for the M-52 and 6.4 for the projected Tu-135 and M-56 missile strike aircraft.

The problems of a heavy aircraft's stability and handling at subsonic, transonic and supersonic speeds and practical methods of balancing the aircraft in these conditions with minimum aerodynamic losses had to be addressed. Sustained flight at Mach 2.0 involved research to achieve the necessary structural strength at airframe temperatures close to 100-120°C (212-248°F); heat-resistant structural materials, lubricants and sealants had to be created, as well as airframe structures able to withstand prolonged kinetic heating, including heating/cooling cycles and the attendant expansion and contraction of the airframe.

The engines had to meet very stringent requirements, being powerful, fuel-efficient and able to run stably in prolonged supersonic cruise; the air intakes and the engine inlets needed to be adjustable for a wide range of altitudes and speeds. The characteristics of the engines and air intakes had to be harmonised with due regard for area-ruling, thus sustaining the required airflow with minimum aerodynamic losses.

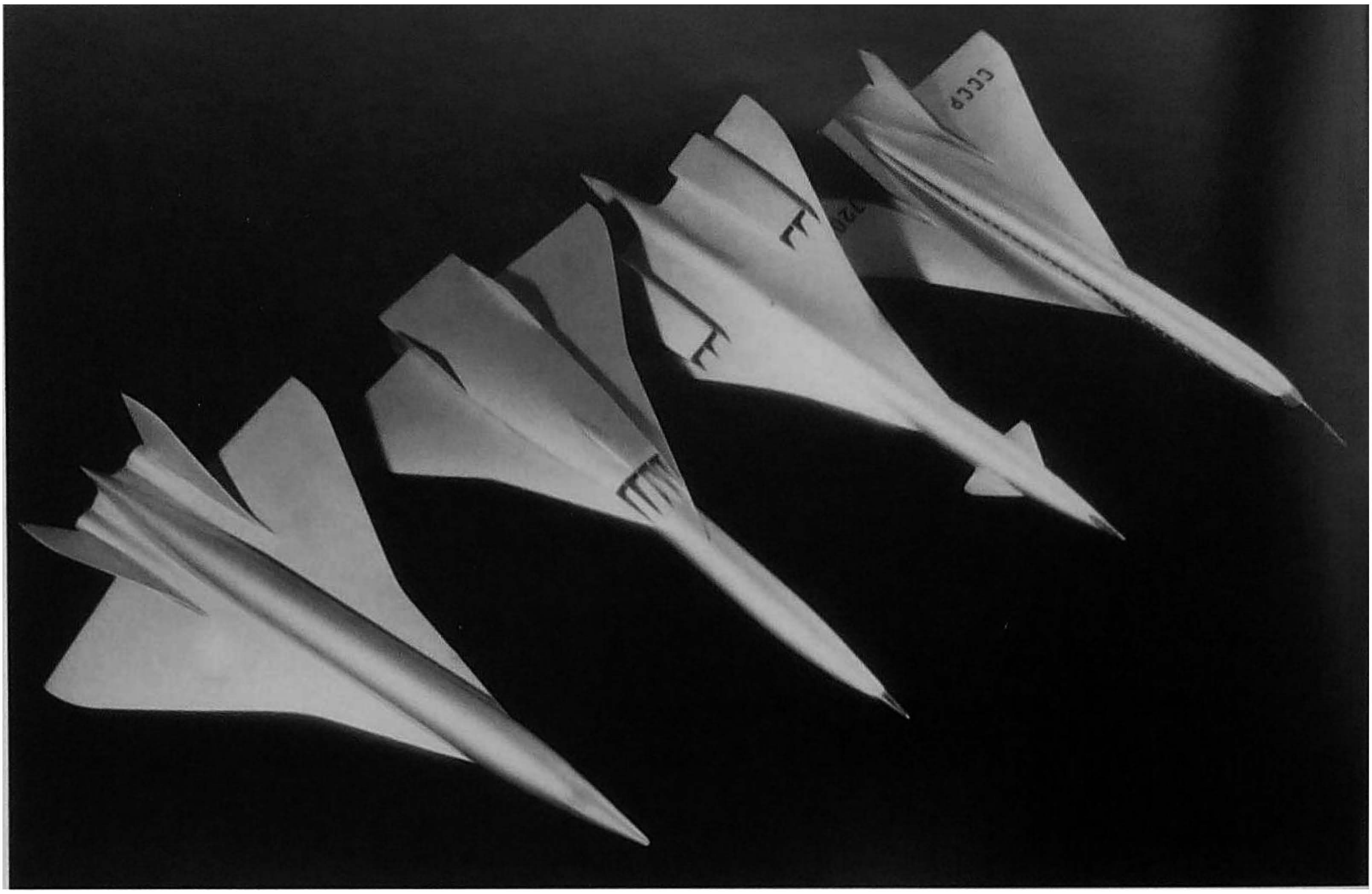
Sustained supersonic cruise was best performed at high altitude; thus, new air conditioning systems and other equipment had to be devised to provide a comfortable environment for the passengers and crew at altitudes up to 20 km (65,620 ft) under conditions of kinetic heating. New avionics enabling automatic flight control, accurate navigation in sustained supersonic cruise and automatic landing were needed. The need arose to study the ecological aspects of SST operations, such as the impact on the ozone layer caused by the large amount of engine efflux at high altitude, as well as the effect of noise and shock waves (sonic boom) on people, animals and ground structures. The effect of solar (ultraviolet) radiation at high altitude on the passengers and crew was another cause for concern. To ensure the SST's trouble-free integration into the existing air transport systems, the peculiarities of Soviet and foreign airline transport practice, as well as of existing airports and air traffic control systems, also had to be taken into account.

All these factors, as well as progress made on SST programmes in the West, were carefully studied at the Central Aero- & Hydrodynamics Institute named after Nikolay Ye. Zhukovskiy (TsAGI – *Tsentrahl'nyy aero- i ghidrodinamicheskiy institoot*), the Tupolev OKB and other OKBs involved. The Soviet supersonic airliner programme named SPS-1 (*sverkhzvookovoy passazheerskiy samolyot pervovo pokoleniya* – first-generation supersonic airliner, or SST-1) was officially kicked off by Council of Ministers/Communist Party Central Committee joint directive No.798-271 issued on 16th July 1963, MAP order No.276 to the same effect following ten days later; the aircraft itself was designated Tu-144. In accordance with these documents the Tupolev OKB was to develop an aircraft which would have the following performance:

- cruising speed – 2,300-2,700 km/h (1,428-1,677 mph);
- seating capacity – 80-100 passengers;
- range with a normal take-off weight of 120-130 tons (264,550-286,600 lb) – 4,000-4,500 km (2,480-2,795 miles);
- range in maximum TOW configuration with 30-50 passengers and external fuel tanks – 6,000-6,500 km (3,730-4,040 miles).

With a normal take-off weight the Tu-144 was to operate from Class A airfields (this means a runway length of 3,250 m/10,660 ft). In maximum TOW configuration a so-called unclassed airfield with a runway in excess of 3,250 m was required.

The Tupolev OKB was tasked with exploring the possibility of giving the Tu-144 intercontinental range enabling non-stop flights to the USA. The CofM directive and the MAP



Four desktop models showing four different general arrangements considered for the Tu-144.

order called for the construction of five Tu-144s in 1966-67, including two static/fatigue test airframes.

As will be seen from the above, the Tu-144 did not meet Aeroflot's requirement of being able to operate the 6,280-km (3,900-mile) Moscow-Khabarovsk service non-stop with a normal payload. Also, the speed specified in the documents mentioned above exceeded the maximum design speed at which relatively cheap and easy-to-use ordinary aluminium alloys with a low heat resistance could be used. Aware of the technical problems (notably those associated with achieving the range required for flying non-stop from Moscow to Khabarovsk), the government authorised the designers to proceed in two stages; an operating range of 4,000-4,500 km was to be achieved initially and then to be extended to 6,500 km in the second stage.

During the time it took to design and build the Tu-144, four Council of Ministers/Communist Party Central Committee directives were passed and more than ten rulings issued by the CofM Presidium's Commission on Defence Industry Matters (VPK – *Voyennopromyshlennaya komissiya*). These documents either revised the design specifications and programme schedule or contained instructions to various enterprises and institutions participating in the SPS-1 programme. More often than not, the deadlines set forth in the documents signed by even the highest-ranking officials were not met – for perfectly legitimate reasons, not because someone was trying to sabotage the programme. With a task of such a grand scale and unprecedented complexity, such delays were inevitable.

In keeping with the aforementioned directive, in 1964 the State Civil Aviation Research Institute (GosNII GA – *Gosoodarstvennyy naoochno-issledovatel'skiy institoot grazhdahnskoy aviahtsii*) issued specifications for the Tu-144; these were duly reviewed and approved by other branches of Ministry of Civil Aviation (MGA – *Ministerstvo grazhdahnskoy aviahtsii*). The performance for the airliner's normal and maximum take-off weight configurations envisaged by this document is indicated in the upper table on the opposite page.

As the work proceeded and the characteristics unique to supersonic airliners were studied, the MGA's specifications were revised accordingly. The definitive version issued in 1965 is illustrated by the lower table on the opposite page.

Of course, the specifications were submitted to General Designer Andrey N. Tupolev for approval. On receiving the specs the Tupolev OKB prepared an advanced development project (ADP) reflecting the Tu-144's two-stage development strategy and submitted it to GosNII GA for review. Stage A envisioned a powerplant consisting of four Kuznetsov NK-144 two-spool afterburning turbofans developed by OKB-276 in Kuibyshev. Derived from the 10,500-kgp (23,150-lbst) NK-8 commercial turbofan, the original NK-144 *sans suffixe* was rated at 17,500 kgp (38,580 lbst) in full afterburner for take-off, with a minimum-afterburner cruise rating of 3,970 kgp (8,750 lbst) and a non-afterburning cruise rating of 3,000 kgp. The anticipated performance of the Tu-144 with these engines is indicated in the upper table on page 15.

Stage B envisaged extending the Tu-144's range and installing a new powerplant consisting of four Kolesov RD36-51A axial-flow non-afterburning turbojets. This version was expected to have the performance stated in the lower table on page 15. It has to be said, however, that many of the performance figures stated in these tables changed considerably as the programme advanced to the detail design stage.

Having carefully studied the ADP, in 1965 GosNII GA drew up a report which basically

approved the project, except for the payload stated for Stage B; the customer (MGA) saw it as inadequate and insisted that the Kolesov-engined version should have a payload of 11-13 tons (24,250-28,660 lb). In 1966 the OKB unveiled a wooden full-scale mock-up of the Tu-144 which was duly examined and approved by an MGA commission.

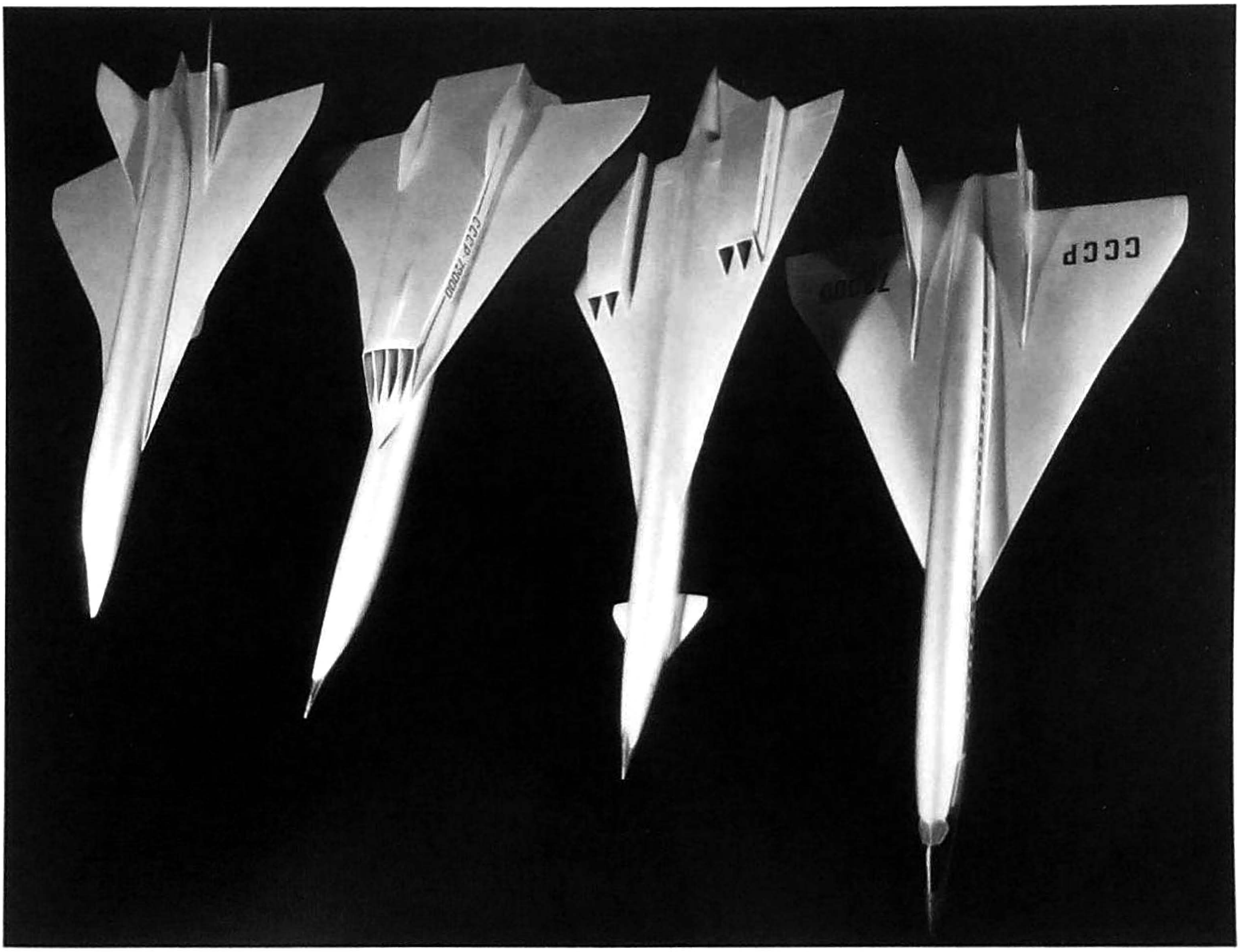
General Designer Andrey N. Tupolev decided to entrust the design work on the Tu-144 to the OKB's Section K which had hitherto been responsible for unmanned aerial vehicles (UAVs). Section K had accumulated adequate experience of designing aircraft capable of sustained flight at speeds in excess of Mach 2, having worked on the '121' ground-launched cruise missile and its reconnaissance drone derivatives – the semi-expendable '123' (DBR-1 Yastreb-1) and the fully recoverable '139' (DBR-2 Yastreb-2); their mission profiles were broadly similar to the Tu-144's envisaged flight profile. Aleksey A. Tupolev, the General Designer's son, was put in charge of the Tu-144 programme. It was under his leadership and with the aid of other

Initial MGA project specifications for the Tu-144 (1964)

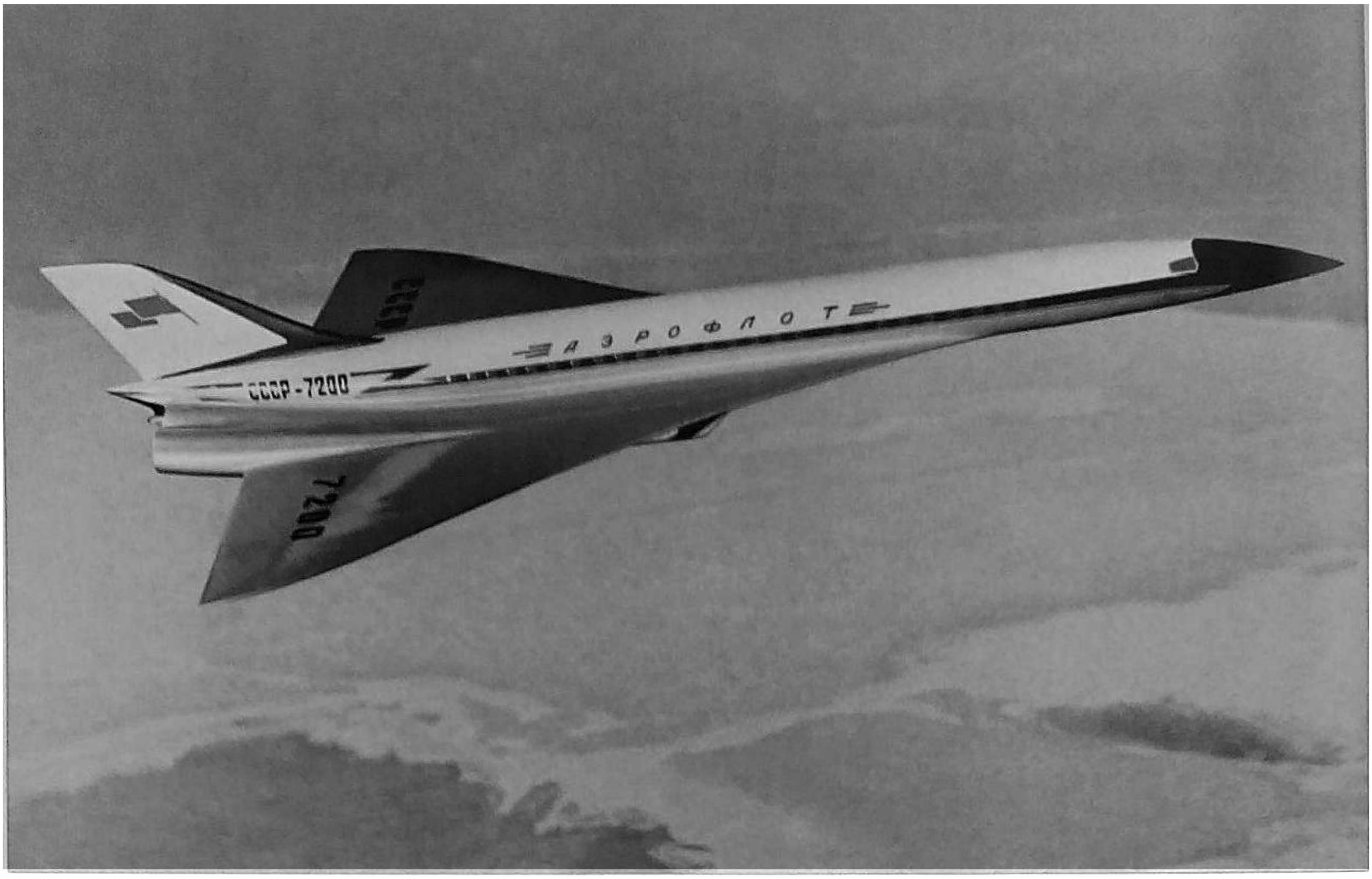
	Normal TOW	Maximum TOW
Seating capacity	120	70-80
Payload, kg (lb)	12,000 (26,455)	7,000-8,000 (15,430-17,640)
Range, km (miles)	4,500 (2,795)	6,300 (3,910)
Take-off run, m (ft)	1,800-2,000 (5,900-6,560)	2,100-2,500 (6,890-8,200)
Take-off weight, kg (lb)	130,000 (286,600)	n.a.
Speed, km/h (mph)	2,100-2,300 (1,304-1,428)	2,100-2,300 (1,304-1,428)
Airfield class	Class A	Unclassed

Revised MGA project specifications for the Tu-144 (1965)

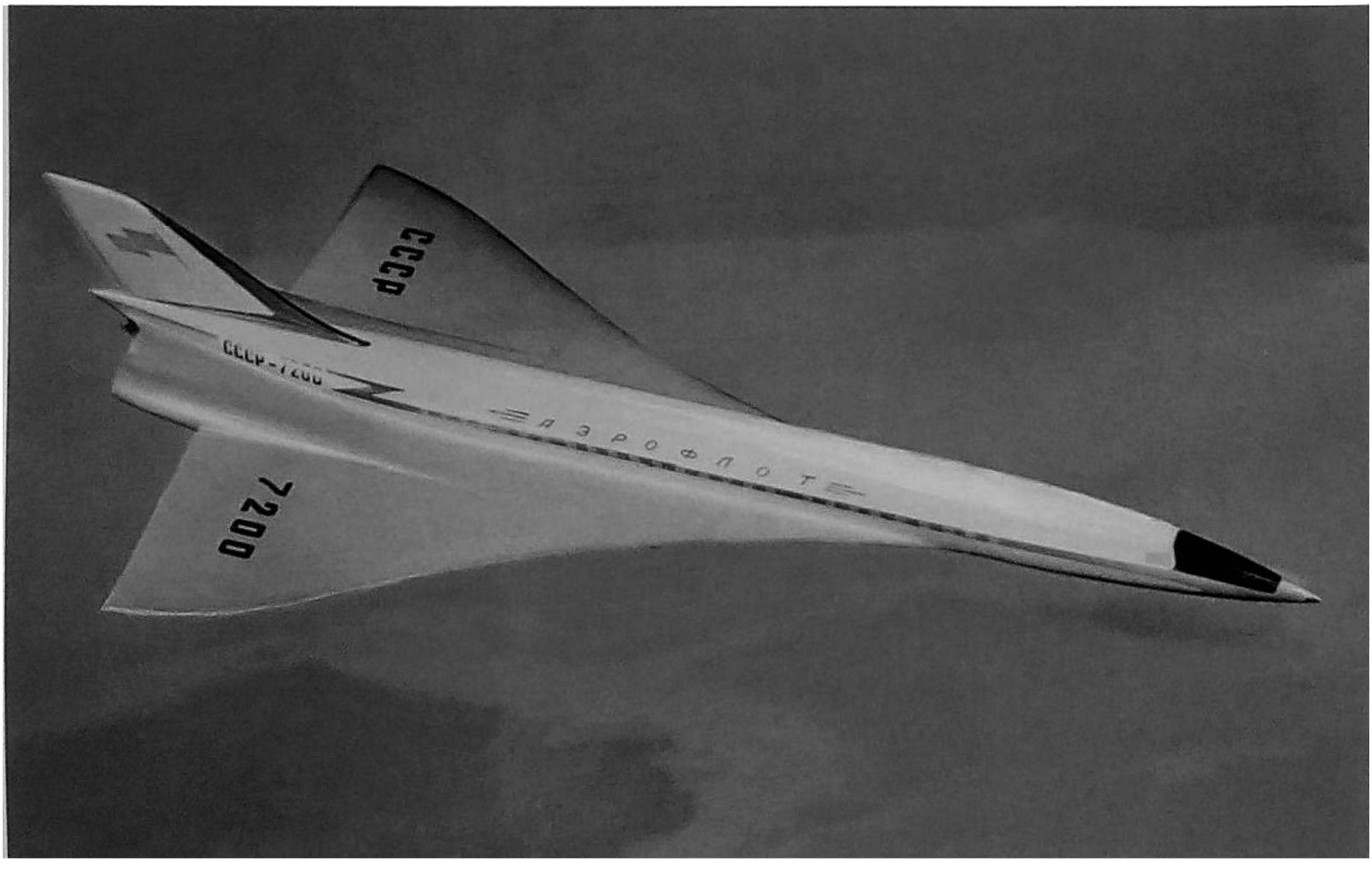
	Normal TOW	Maximum TOW
Range, km (miles)	4,500 (2,795)	6,500 (4,040)
Payload, kg (lb)	14,000-15,000 (30,860-33,070)	11,000-13,000 (24,250-28,660)
Seating capacity (including 16 first-class seats)	150	110
Take-off weight, kg (lb)	150,000 (330,690)	180,000 (396,825)
Airfield class	Class B (runway length 2,600 m/8,530 ft)	Class A (runway length 3,250 m/10,660 ft)



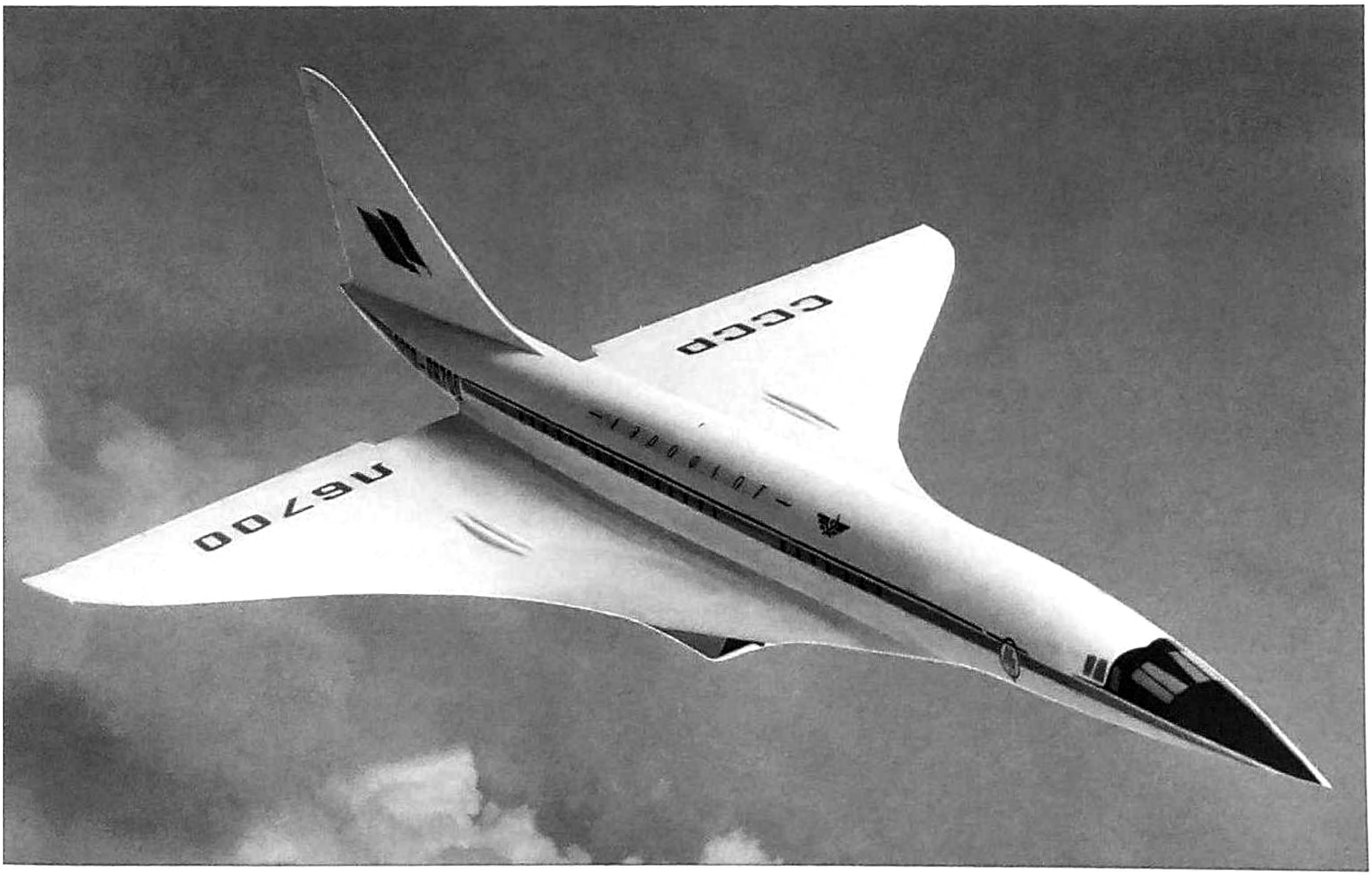
Another aspect of the models on the opposite page; none of the models appears to have a drooping nose. Note the position of the nose gear unit on the No.2 model. If it weren't for the canards, No.3 would be a virtual copy of the Concorde.

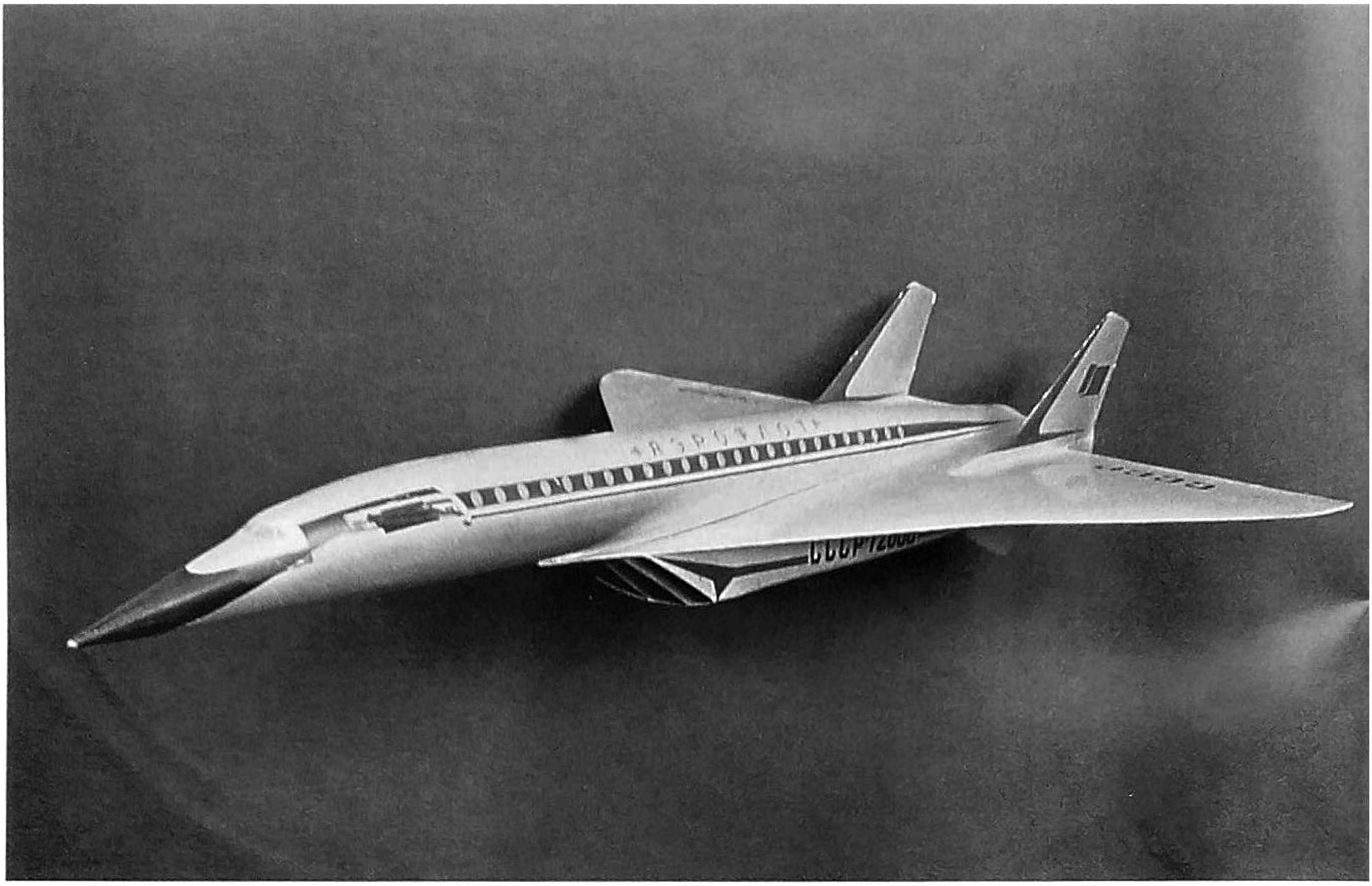


Above and below: An artist's impression showing one of the early project configurations. Note the very short rear fuselage and the way that the engine inlet ducts/engine bays 'blend through' the wings, the nozzles terminating just short of the tailcone. The fin has trailing-edge sweep.

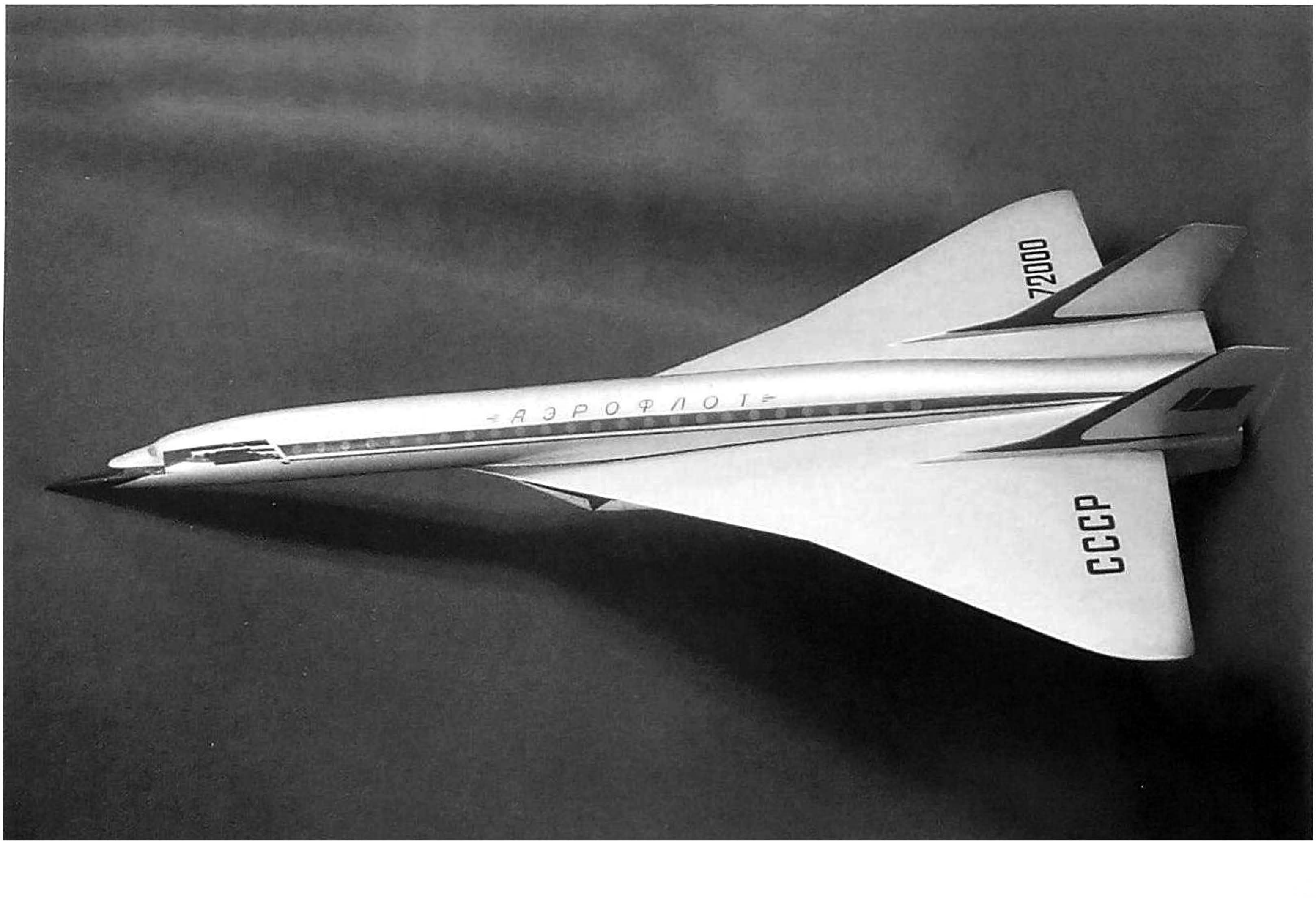


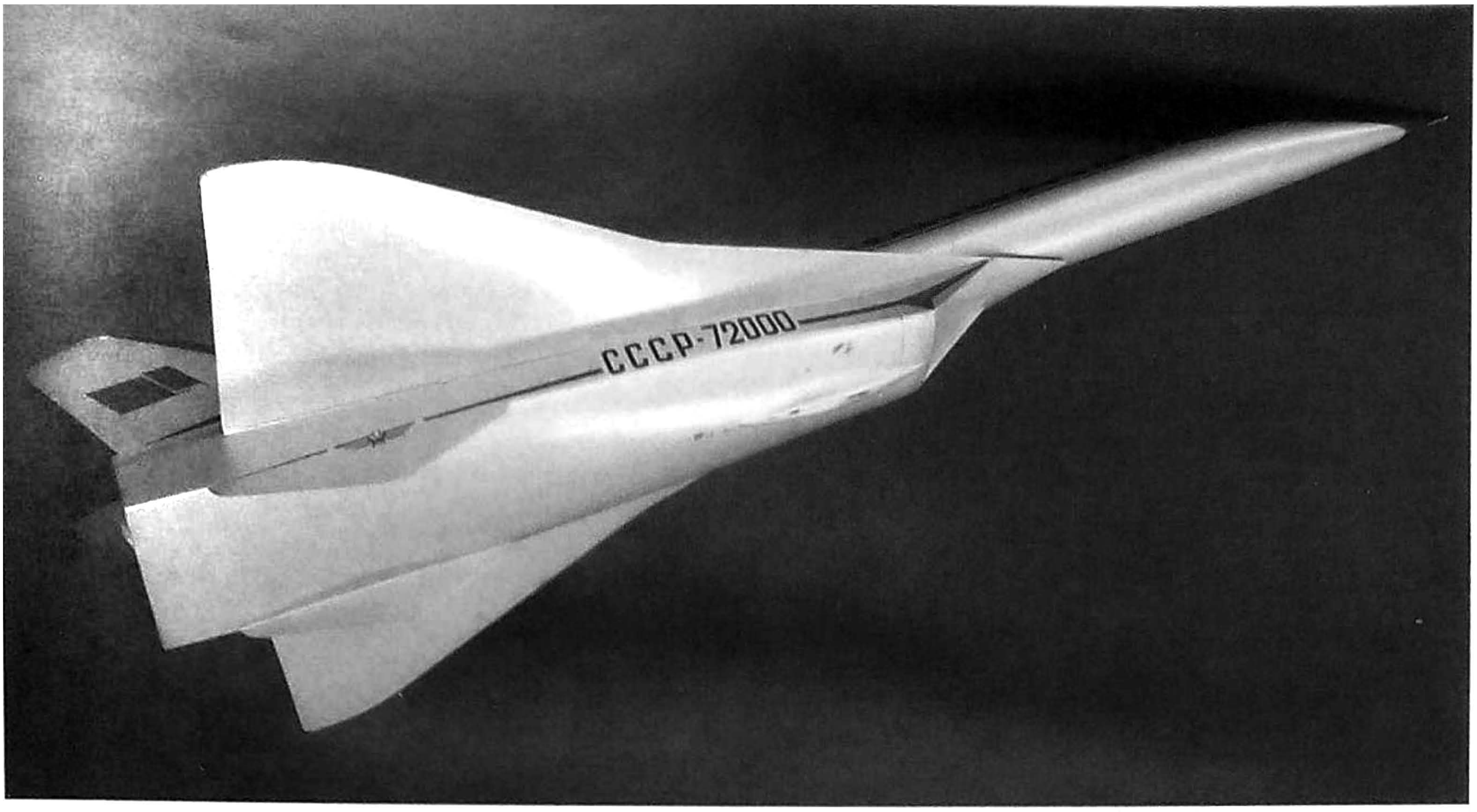
Above and below: This model shows the Tu-144 prototype as eventually built. The differences are obvious. The creases on the wings' upper surface are bulges for the main gear wheels.





Above and below: Another preliminary design configuration featuring twin tails and ventral strakes. This version looks definitely overweight.
Right: A lower view of the same model, showing the nose gear unit fairing aft of the air intake assembly and the boxy fairing around the engine nozzles.





gifted designers that the concept and future shape of the Tu-144 took shape. After Andrey N. Tupolev's death in 1972 and the appointment of Aleksey A. Tupolev as head of the OKB, Yuriy N. Popov and B. A. Gantsevskiy headed the Tu-144 programme. Later, overall responsibility for the Tu-144 passed to A. L. Pookhov who, as a young engineer, had made a major contribution to the design effort in the 1960s.

The actual design process was headed by Valentin I. Bliznyuk, who later became famous as the programme chief of the Tu-160 strategic missile strike aircraft. G. A. Cheryomukhin (later the Tupolev OKB's chief aerodynamicist) was responsible for selecting the optimum general arrangement for the Tu-144, working in close contact with his colleagues at TsAGI. Integration of the powerplant's components (engines, air intakes and so on) jointly with the Central Aero Engine Institute (TsIAM – *Tsentrahl'nyy institoot aviatsionnovo motorostroyeniya*) and the Kuznetsov OKB was the responsibility of a team headed by V. M. Vool'. Gradually, as the scope of the design work widened, other sections of the Tupolev OKB were called upon to participate in the project. Soon the Tu-144 became one of the OKB's (and generally MAP's) most important programmes for the decade that followed.

The Tu-144's aerodynamics were largely determined by the need to achieve long range in supersonic cruise while ensuring adequate stability and handling and providing the required field performance. Taking the specific fuel consumption (SFC) of the NK-144 engine advertised by OKB-276 as the starting point, the designers strove to achieve a maximum cruise lift/drag ratio of 7 at the first stage of the programme. Taking into consideration the financial, technological and weight factors, a cruising speed of Mach 2.2 was selected.

The OKB and TsAGI considered several dozen alternative layouts at the preliminary design (PD) stage. A conventional layout was rejected because the horizontal tail would generate up to 20% of the overall drag. The idea of a tail-first (canard) design similar to the Tu-135 was similarly rejected because of the adverse effect the canard foreplanes would have on the wings.

The choice finally fell on a low-wing tailless-delta design with a conventional fin/rudder, a common ventral housing for all four engines and a tricycle undercarriage. The wings had an ogival planform, the leading-edge sweep being 78° on the inboard portions and 55° on the outboard ones; the wing planform was dictated by the need to minimise the shift of the wings' aerodynamic centre during the transition from subsonic to supersonic flight and back again. The vertical tail had a similar shape.

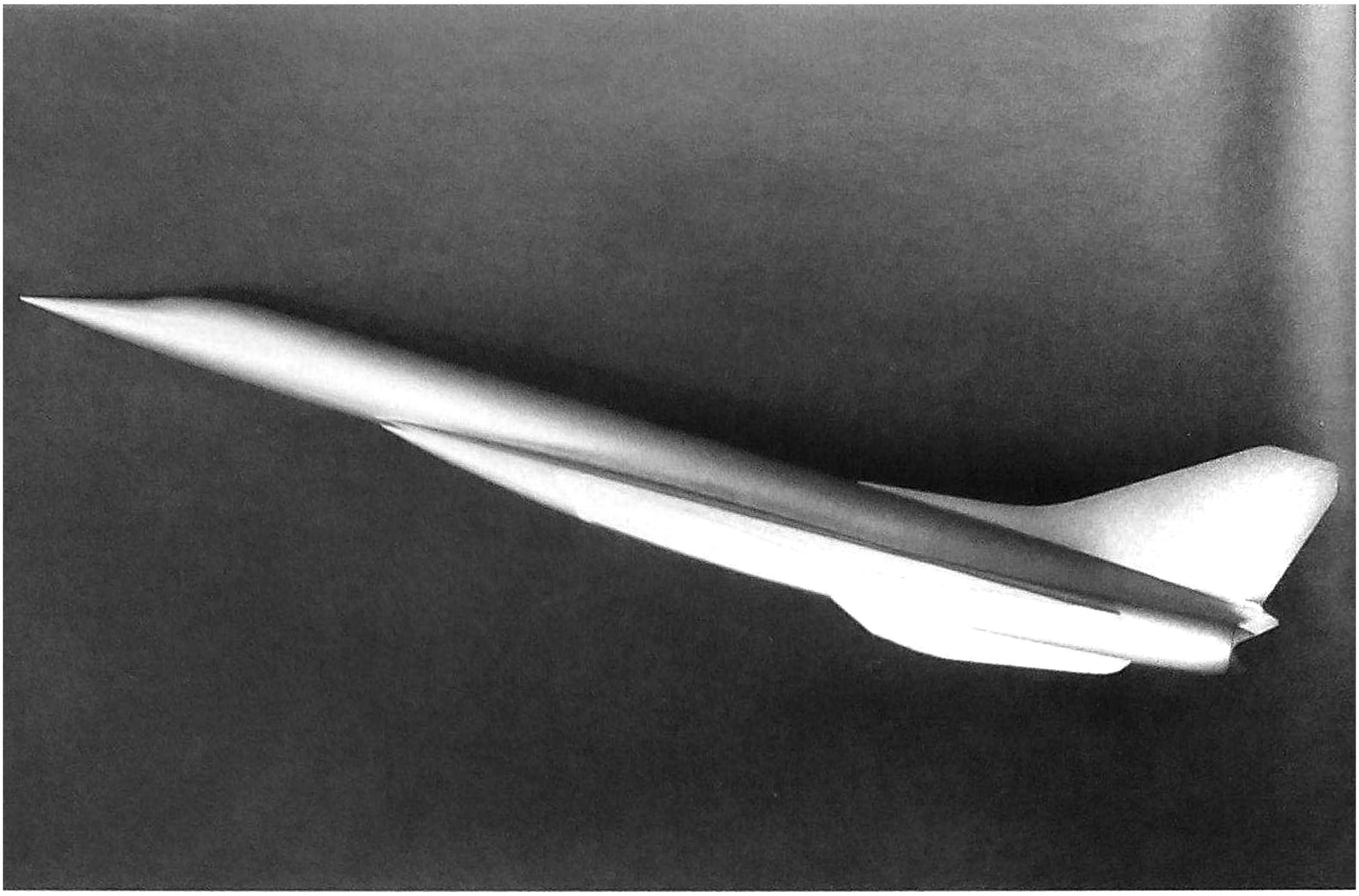
The basic details of the Tu-144's aerodynamic layout warrant a more detailed description. The wider an aircraft's speed envelope is, the harder the task of the designers who inevitably have to make compromises when choosing the aerodynamic layout. In the case of the SST the compromises are particularly difficult because of the fundamental difference in the aircraft's aerodynamics in

Tu-144 project performance with Kuznetsov NK-144 engines (stage A)

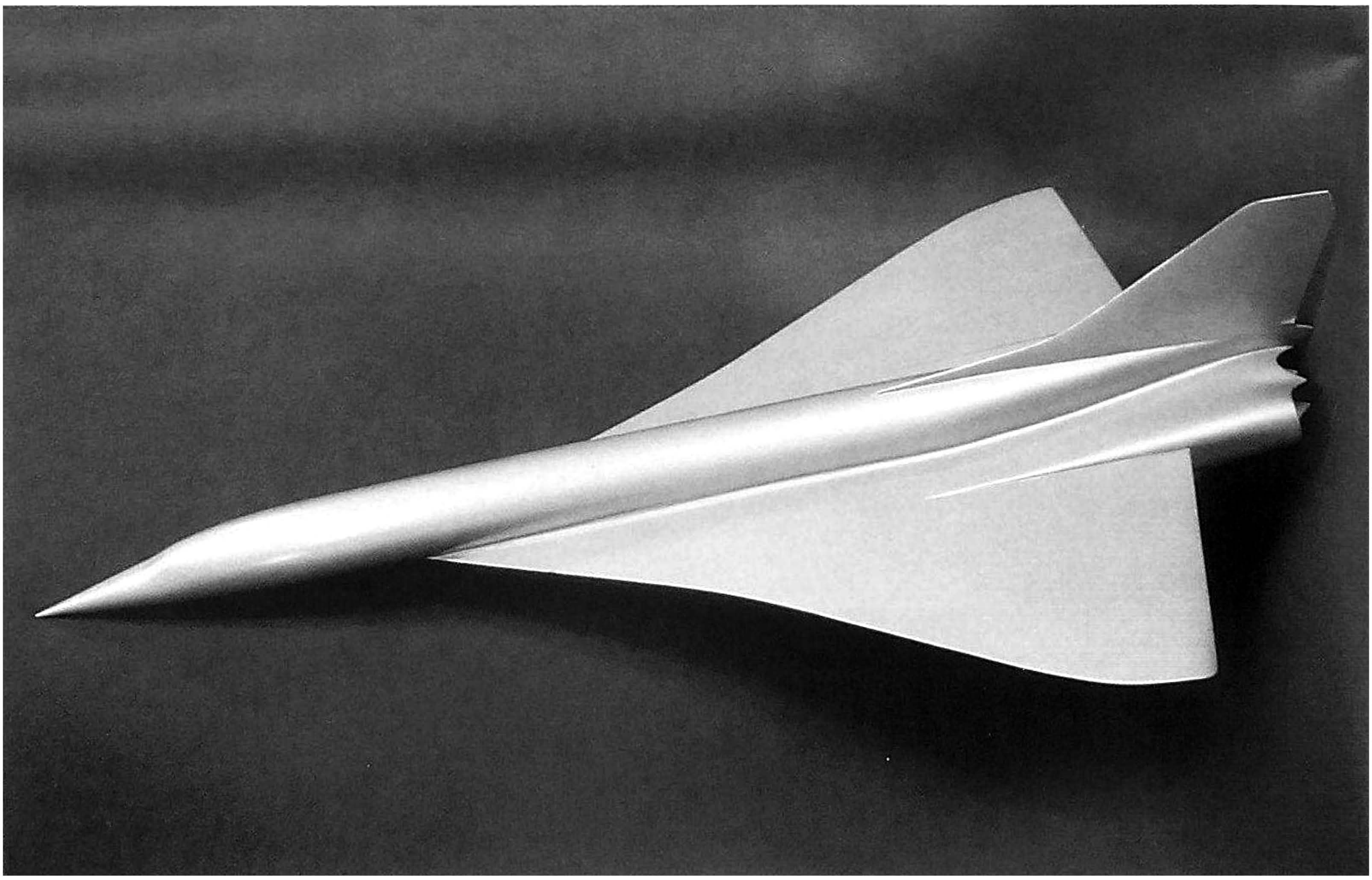
Take-off weight	150,000 kg (330,690 lb)
Payload	14,000-16,000 kg (30,860-35,270 lb)
Seating capacity	150
Crew	5
Service altitude	18,500-20,500 m (60,695-67,260 ft)
Cruising speed	2,500 km/h (1,552 mph)
Range	4,515 km (2,804 miles)
Take-off run	1,720 m (5,640 ft)
Landing run	1,330 m (4,360 ft)
Unstick speed	350 km/h (217 mph)

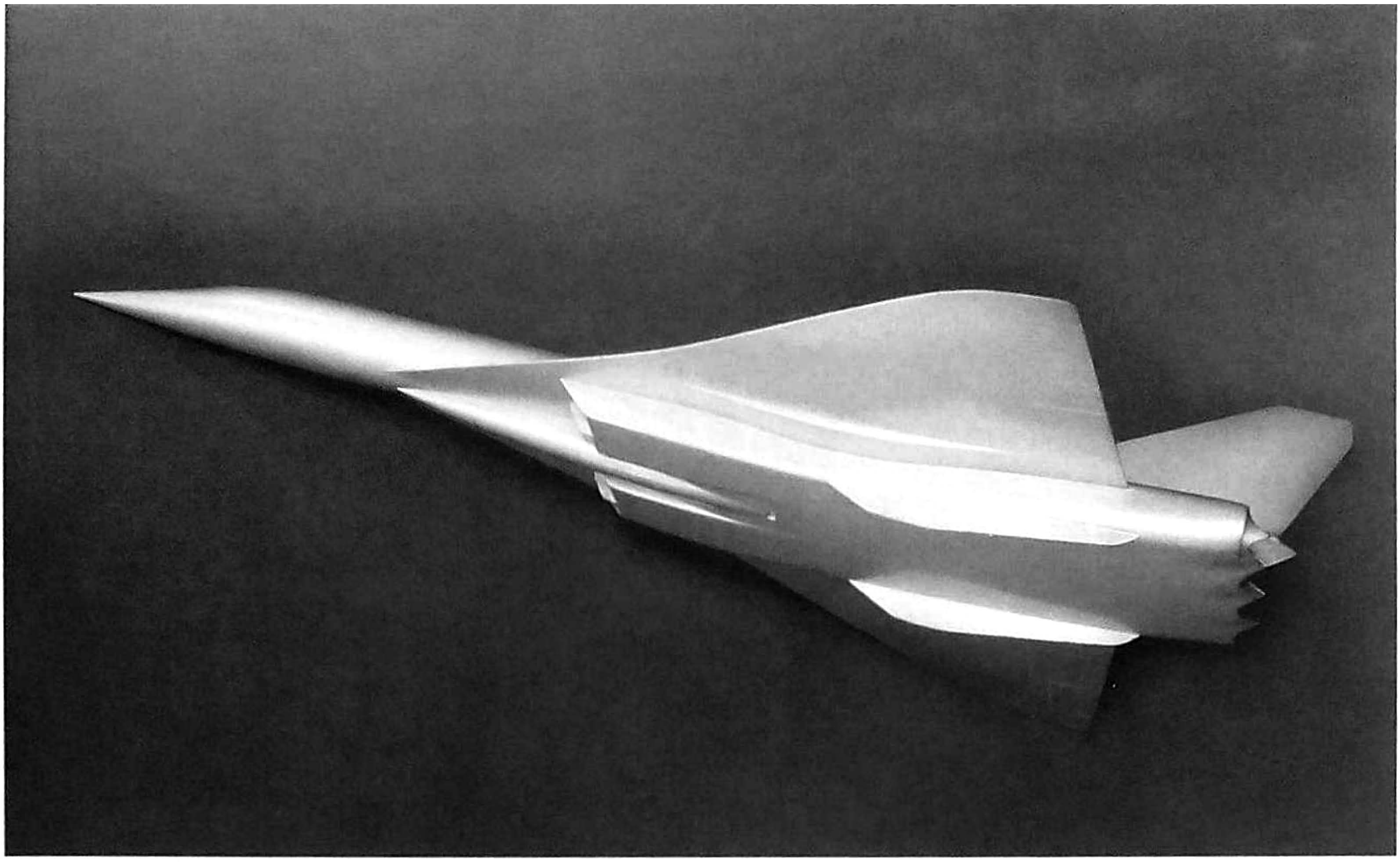
Tu-144 project performance with Kolesov RD36-51A engines (Stage B)

Take-off weight	180,000 kg (396,825 lb)
Payload	8,000 kg (17,640 lb)
Seating capacity	80
Airframe weight	78,000 kg (171,960 lb)
Fuel load	94,000 kg (207,230 lb)
Range	6,510 km (4,043 miles)
Service altitude	18,500-20,500 m (60,695-67,260 ft)
Cruising speed	2,500 km/h (1,552 mph)
Take-off run	2,370 m (7,775 ft)
Landing run	1,440 m (4,720 ft)
Unstick speed	380 km/h (236 mph)
Fuel consumption	24-25 tons/hr (52,910-55,115 lb/hr)



bove and below: This model shows yet another of the Tu-144's preliminary design configurations. Note the trapezoidal vertical tail and the forward sweep on ıe wing trailing edge.





Another view of the same model, showing the large nose gear fairing blended into the engine nacelle, the ventral strakes and the 'pen nib' fairings between the engine nozzles. The bulges in the wing undersurface outboard of the nacelle house the main gear units.

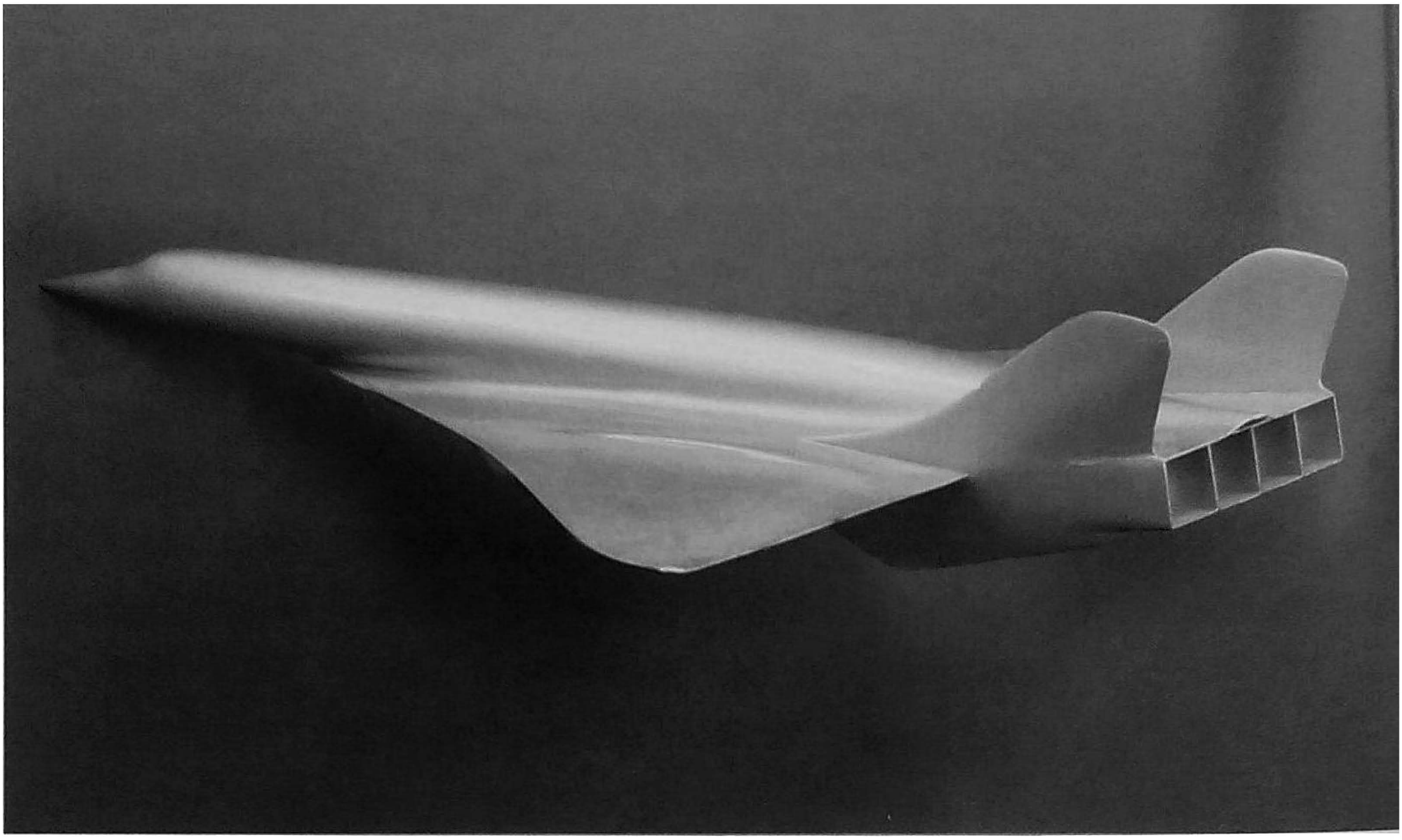
subsonic and supersonic flight. Hence several research institutes contributed their expertise to the shaping of the Tu-144's aerodynamics; TsAGI co-ordinated the work and had the final say in order to avoid a 'too many cooks' situation.

It is a universal truth that any aircraft – and that includes SSTs – should be balanced, stable and adequately controllable in flight. Subsonic aircraft usually have separate horizontal tail surfaces mounted aft of the wings. If the wings have a very wide chord they may be 'blended' with the horizontal tail into a single whole, with combined trailing-edge surfaces for pitch/roll control called elevons supplanting the usual elevators and ailerons. This is known as the tailless layout (or tailless-delta layout, since such aircraft invariably have delta wings). World aircraft design practice and the results of the Tupolev OKB's own research performed by the early 1960s indicated that the tailless-delta layout was the best choice for a supersonic airliner. However, this layout had many influential opponents in high places. Using his friendship with the OKB-155 'fighter maker' design bureau's General Designer Artyom I. Mikoyan, Andrey N. Tupolev asked him to build a subscale proof-of-concept vehicle for the Tu-144. Known as the MiG-21I (*issledovatel'skiy* – research, used attributively), this aircraft – a production MiG-21S fighter refitted with a scaled-down version of the Tu-144's wings – flew successfully and any remaining doubts about the suitability of the tailless-delta layout were dispelled.

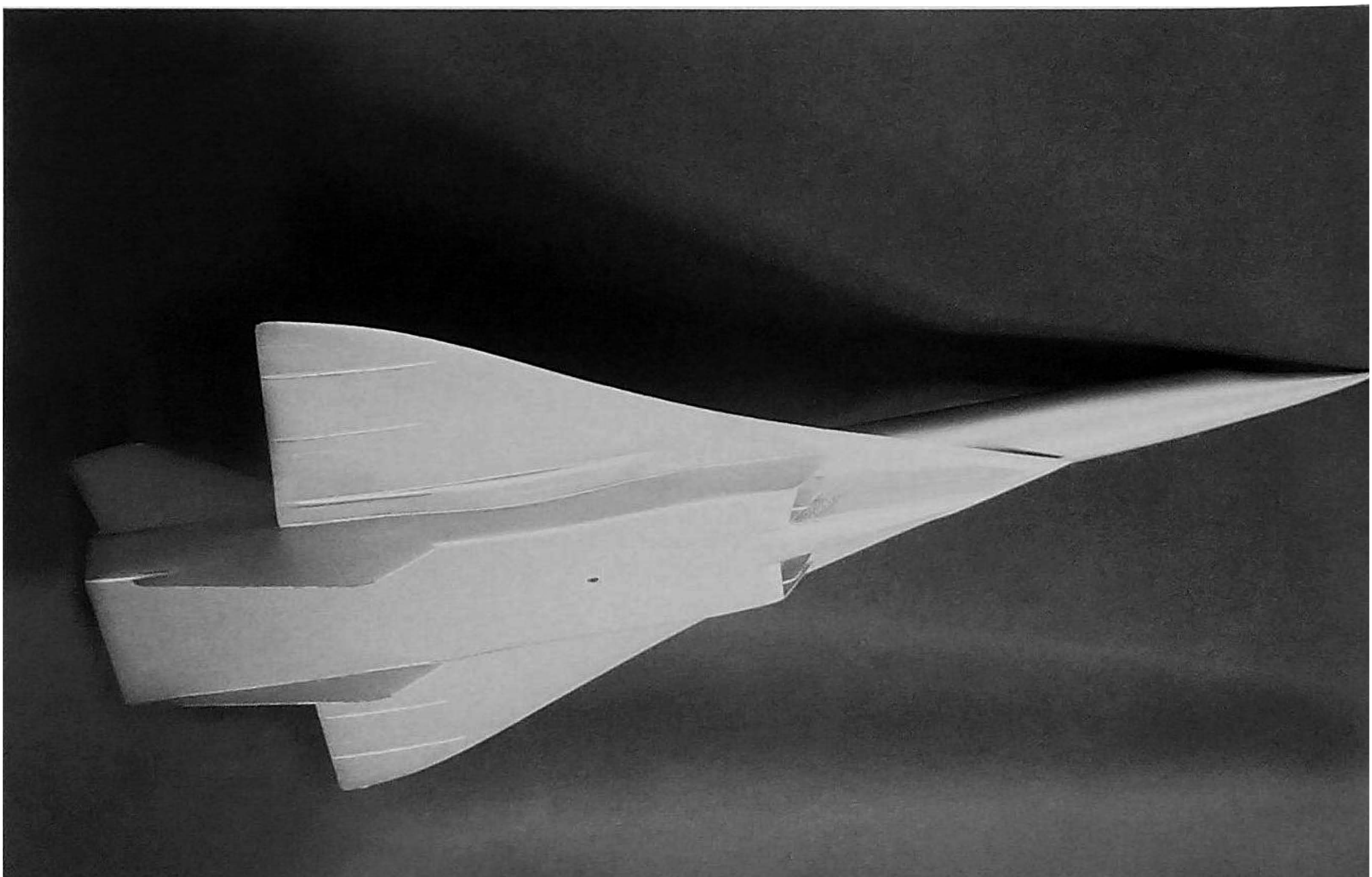
The requisite lift/drag ratio could be obtained and the aircraft balanced with minimum aerodynamic losses by selecting the correct wing planform and airfoils. No theory explaining how to choose them existed as yet, and the quest for the optimum wing planform and airfoils for the future Tu-144 was guided by the following considerations. Sharply swept leading-edge root extensions (LERXes) would extend acceptable stability and handling over a wider range of speeds, create an upwash on the main portions of the wings, reduce the overall thickness/chord ratio at the roots while retaining the same depth of the wing structure and help to accommodate the fuel tanks in such a way that their aggregate centre of gravity would coincide with the aircraft's requisite CG position. The spanwise distribution of the lift across the wings should be as close as possible to an elliptical pattern, so should the distribution of the lift along the aircraft's length. The lengthwise distribution of the cross-section area should be as close as possible to a minimum-drag axisymmetrical object (this is known as the 'area rule').

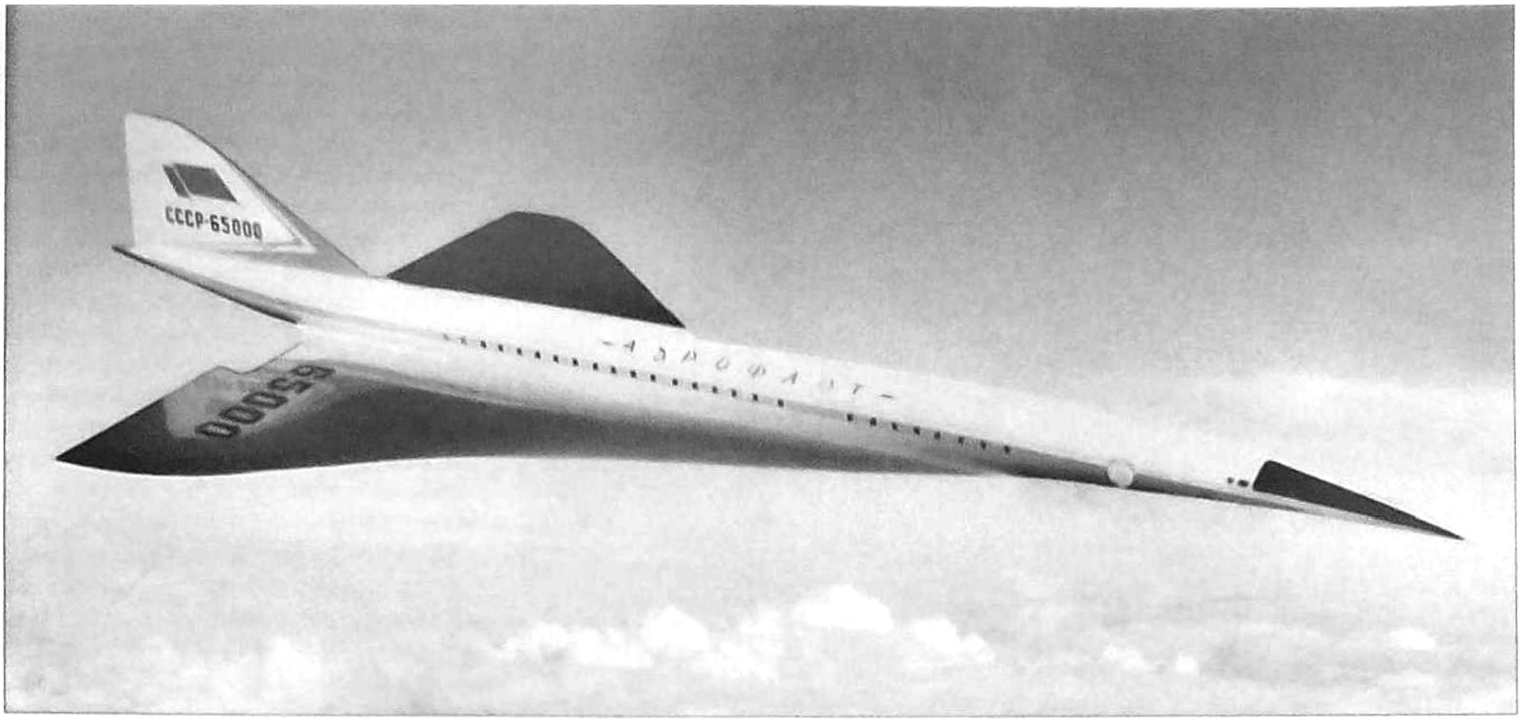
Having found proof positive of their ideas by testing several dozen models in TsAGI's wind tunnels in co-operation with the institute's researchers (Steiner, Vasil'yev, Shooryghin and Belotserkovskiy), the Tupolev OKB's aerodynamics section (Cheryomukhin, Pookhov, Rafaelyants, Koshcheyev, Zhookova, Govor, Strizhenov *et al*) developed the future Tu-144 prototype's wing shape. Their main objective was to obtain the required cruise lift/drag ratio of about 7 without compromising field performance.

Speaking of field performance, since the production Tu-144 was expected to be heavier than the prototype, the designers had to seek ways of increasing the wing lift in the take-off and landing modes to make up for this. Apart from a slight increase in wing area, after considering several alternative versions of high-lift devices the designers settled for deflecting the elevons 10° down in flap mode and leaving another 10° of downward travel for roll control as the most effective and most realistic option. However, lowering the elevons created a pitch-down force, which had to be compensated. After studying various options once again, the OKB decided to incorporate retractable canard foreplanes which would be deployed in concert with the elevons – a feature not found on any previous aircraft.



Above and below: This model shows a configuration with short twin tails and ventral strakes flanking a boxy structure housing the engine nozzles. Again, the pairs of air intakes are divided by a large nose gear fairing.



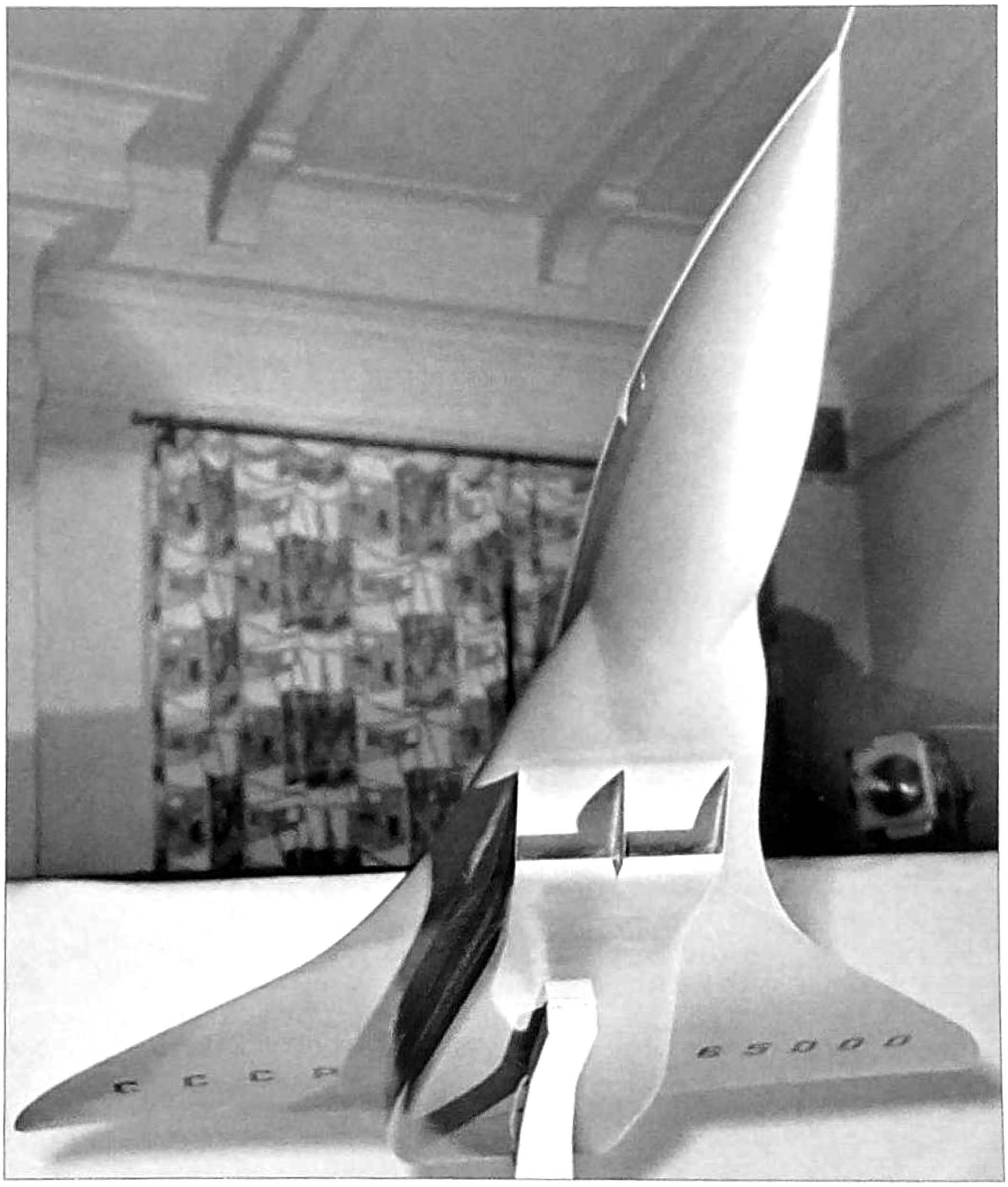


Above: The final configuration of the Tu-144 in which the prototype was built.

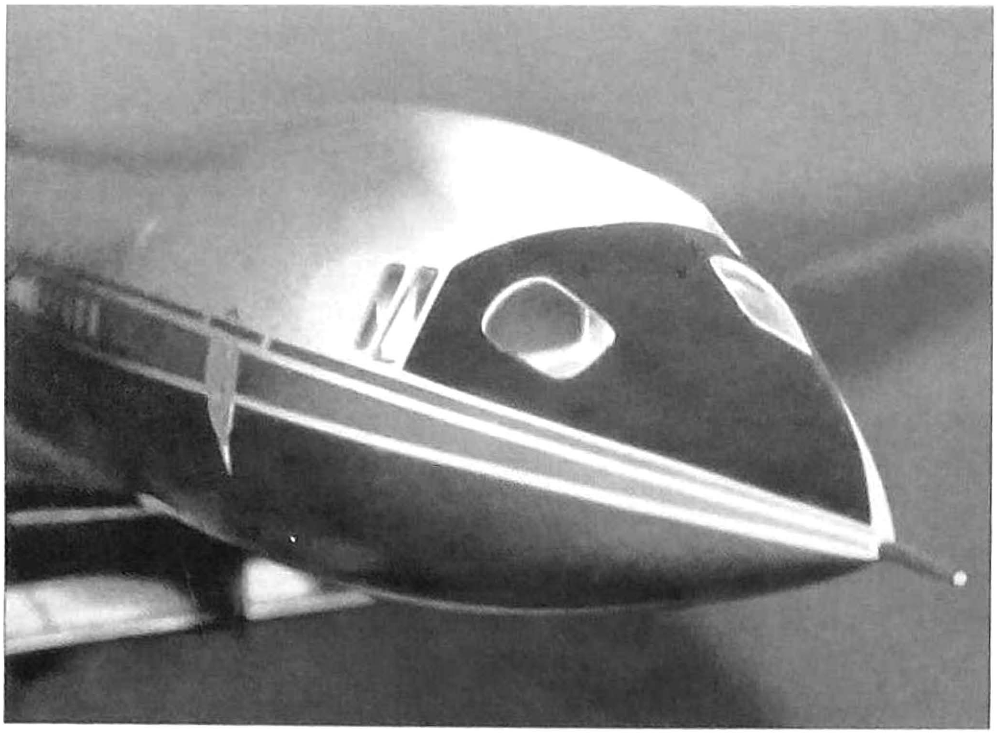
Eventually the wing geometry of the production-standard Tu-144 ended up being rather different from the prototype's (see next chapter for a more detailed comparison of the two models – the difference was not limited to the wings). The production model's wing leading-edge sweep was reduced by 2° on the LERXes and increased by 2° on the outer wings (to 76° and 57° respectively); the wing camber axis was moved from the rearmost wing spar to the foremost spar and the wings were given negative incidence. It was mostly the new wings that accounted for the 10% improvement in the lift/drag ratio as compared to the prototype.

To reduce the effect of the canard foreplanes on the Tu-144's longitudinal stability it was necessary to maximise the canards' specific lift (per unit of area) and minimise the influence of the aircraft's angle of attack (AOA) on this lift. After a period of intensive and painstaking research and development work the OKB's aerodynamicists and engineers (coached by TsAGI) came up with an ingenious solution: the canards, whose area equalled only about 2% of the wing area, were fitted with double-slotted (!) leading-edge slats and double-slotted flaps. To minimise the AOA's influence and improve the lift/drag ratio in take-off and landing modes the canards had 15° anhedral when deployed.

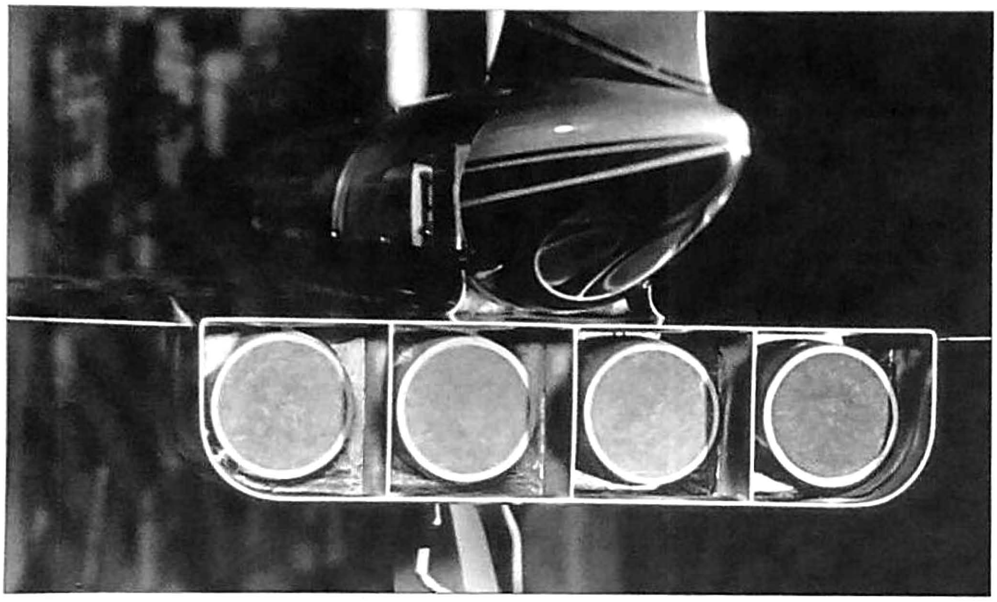
Choosing the optimum contours and internal layout of the engine nacelles (or nacelle, in the case of the prototype) turned out to be no easy task either. The engine manufacturer placed high demands on the stability of the airflow at the compressor faces, which necessitated the use of long inlet ducts and required the engine nacelle(s) to fit within



This model depicts the penultimate configuration, since the intakes are located all together with no gap for the nose gear unit. Note the area ruling of the nacelle.



Above: The forward fuselage of the model on the previous page, showing the windows in the drooping nose enabling forward vision in cruise flight. Note the pitot at the tip of the nose.



The boxy structure around the same model's engine nozzles, separated by the engine firewalls.

the width of the wing LERXes. The gap between the production aircraft's engine nacelles was carefully shaped for minimum drag, with due regard to the air intakes' boundary layer spill ducts and the wing/intake interference; as a result, the Tu-144's large nacelles were just a little more draggy than the Concorde's smaller nacelles featuring short inlet ducts. Much effort was spent on perfecting the fuselage contours, too. For instance, in common with the Concorde the Tu-144 had an unpressurised pointed extreme nose section ahead of the flightdeck which could be depressed hydraulically to improve visibility on take-off and landing – a must, since the low aspect ratio wings resulted in a high AOA on approach. This drooping nose was painstakingly tested in TsAGI's wind tunnels to select the optimum deflection angles, improving the overall lift/drag ratio.

To make a long story short, the combined effect of all the measures taken by the Tupolev OKB and TsAGI gave the production Tu-144 a cruise lift/drag ratio 8-10% better than the Concorde's, according to published reports. This was due in no small degree to the persistent efforts aimed at achieving a high-quality surface finish, much attention having been paid to rivet lines, skin joints, pitot heads, aerials and the like. It should be noted that the Tu-144 was unique among Soviet aircraft in this respect, meeting TsAGI's surface finish requirements in full; all other Soviet types were manufactured fairly crudely (by Western standards anyway), the drag caused by the poor surface finish exceeding the limits set by TsAGI two to three times. The excellent aerodynamics of the production Tu-144 stemmed not only from the thousands of pages of calculations but also from the results obtained with 250-plus models in wind tunnels across the nation – from Riga in the west to Novosibirsk in the east.

The first SSTs were developed and put into service at a time when ecological awareness was heightened and the regulations concerning the environmental impact of commercial aircraft were tightened dramatically. The Tu-144 emerged as the winner in this respect as well, since its design features reduced noise pollution; the retractable canards made for a lower approach speed and helped to reduce ambient noise levels on take-off and landing, while the long engine nacelles and inlet ducts reduced the severity of the Tu-144's sonic boom.

Developing the Tu-144's powerplant was one of the biggest challenges, the problems to be tackled being the creation of the optimum engine, the need for highly complex fully adjustable supersonic air intakes and the strong heating of the air and the fuel entering the engines. At the cruising speed of Mach 2.2 the air temperature at the engine compressor faces exceeded 153°C (307°F). The Tupolev OKB performed a large amount of research and development work jointly with TsAGI, TsIAM, the Flight Research Institute named after Mikhail M. Gromov (LII – ***Lyotno-issle*dovatel'skiy *instit*oot**) and other research institutions in order to resolve these issues. Success in these matters was assured, among other things, by the OKB's well-established practice of checking out the new engines on ground rigs and flying testbeds before installing them in actual prototype aircraft.

Initially the Tu-144's powerplant was the department of K. V. Minkner, one of the Soviet Union's most prominent specialists in the field of aircraft propulsion technology. After his death in harness, V. M. Vool' took over the job in March 1972.

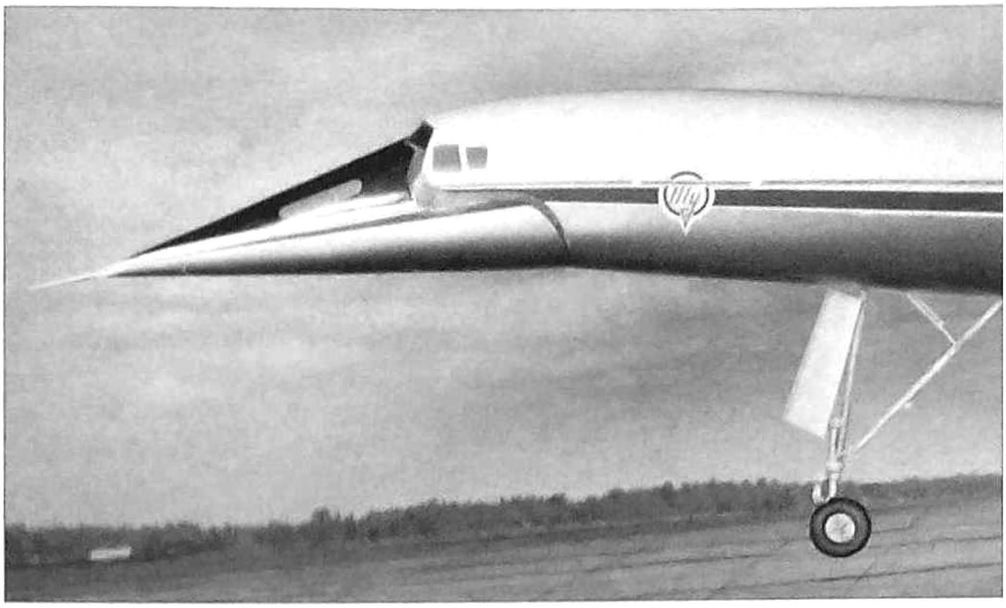
Generally it takes longer to develop an aero engine from scratch than it takes to design an all-new airframe; and the common wisdom is that you design an aircraft around the engines, not vice versa. Therefore, it is easy to see why Andrey N. Tupolev accepted the offer of OKB-276 General Designer Nikolay Dmitriyevich Kuznetsov to develop the NK-144 afterburning turbofan with a bypass ratio of 0.6 as a derivative of the NK-8 powering the Tu-154 and Il'yushin IL-62 airliners – an idea supported by TsIAM and TsAGI. The proven core of the NK-8 meant that the NK-144 would be a reliable engine with ample

thrust reserves – exactly what the Tupolev OKB needed for testing and perfecting the SST. Nikolay D. Kuznetsov had made his mark as a gifted designer and a good co-ordinator back in the early 1950s by designing the unique TV-12 (NK-12) turboprop engine powering the Tu-95/Tu-142 bomber/anti-submarine warfare aircraft family, the Tu-114 airliner and its Tu-126 airborne early warning and control (AEW&C) derivative, and the Antonov An-22 heavy transport. Now he had a chance to prove this image of his once again by overcoming the many organisational and technical problems that would inevitably crop up when creating such an engine.

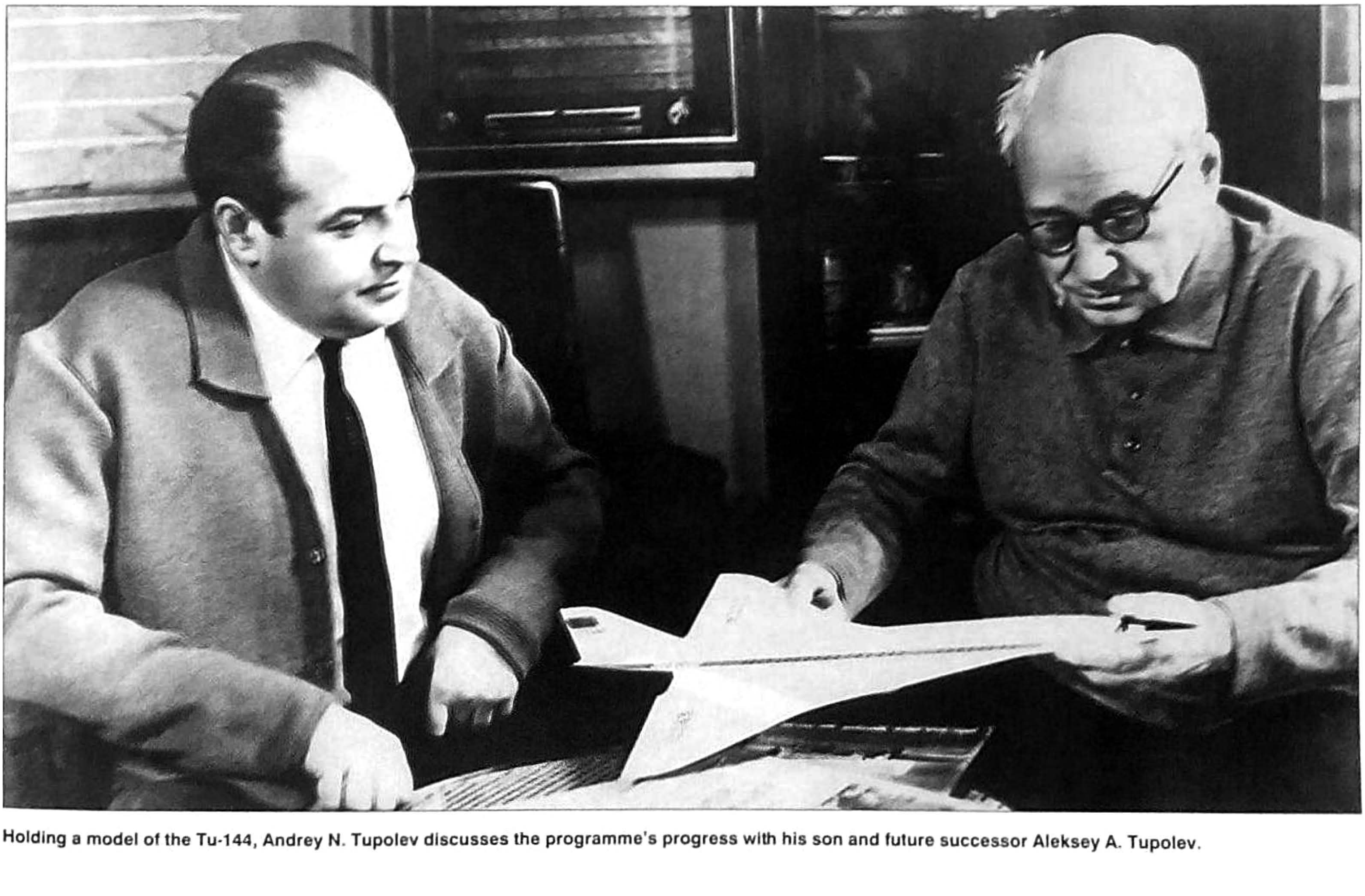
It may well be said here that production Tu-144s *sans suffixe* were powered by improved NK-144A engines uprated to 20,000 kgp (49,020 lbst) for take-off, with a cruise SFC of 1.81 kg/kgp·hr at Mach 2.2. This was necessitated by the production version's higher weight. The NK-144A eliminated the original version's shortcoming of inadequate surge resistance; the next version (the NK-144V) achieved the mass flow and SFC figures specified by the customer but came too late to power the Tu-144, as the programme had been closed down in the meantime.

In 1967 the OKB-36 aero engine design bureau in Rybinsk headed by Pyotr Alekseyevich Kolesov was tasked with developing the RD36-51A non-afterburning turbojet having a take-off rating of 20,000 kgp and a cruise SFC of 1.23 kg/kgp·hr at Mach 2.2. This engine had a number of interesting technical features (variable compressor stator vanes, a lightweight and efficient variable nozzle with a translating centrebody, an accessory gearbox installed separately from the engine and driven by an extension shaft and so on); provision was made for fitting thrust reversers and noise attenuators later on.

The fuel load (up to 100 tons/220,460 lb) was to be housed in seven main tanks and four service tanks. The usual centrifugal pumps were to be augmented by jet pumps transferring fuel from the bottom of the tanks and acting as a back-up. Much attention was paid to the reliability and operational safety of the fuel system; in particular, nitrogenated fuel was used to reduce the fire hazard in kinetic heating conditions (the fuel was saturated with nitrogen during the refuelling procedure, giving off nitrogen during the climb and in cruise flight).

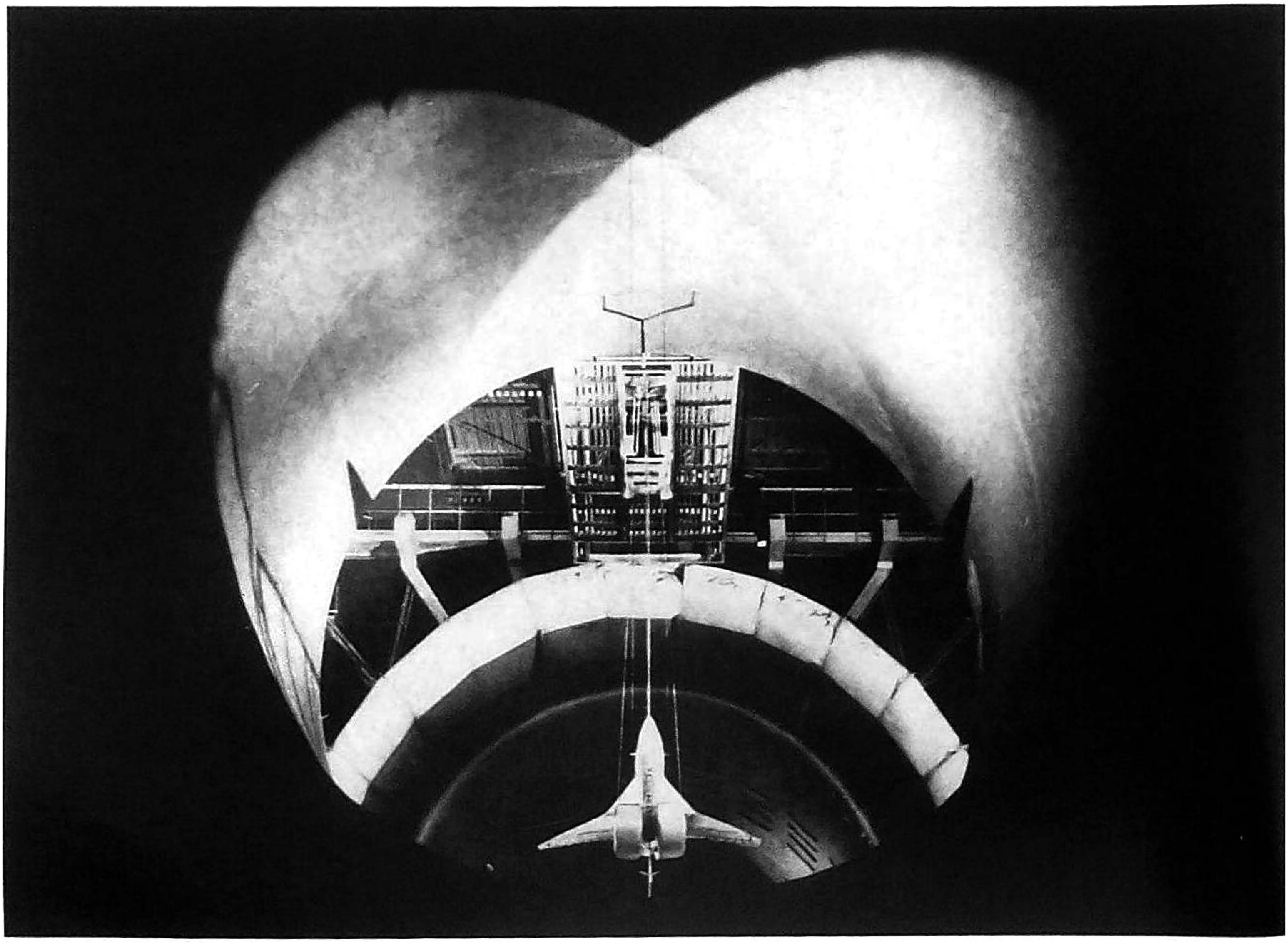


Above: The forward fuselage of the same model with the nose visor drooped. Note the location of the nose gear unit well ahead of the engine air intakes.



Holding a model of the Tu-144, Andrey N. Tupolev discusses the programme's progress with his son and future successor Aleksey A. Tupolev.

Above: Aleksey A. Tupolev (right) discusses the Tu-144 programme at an MAP meeting. Judging by his father's facial expression, the tone of the discussion is not at all friendly...

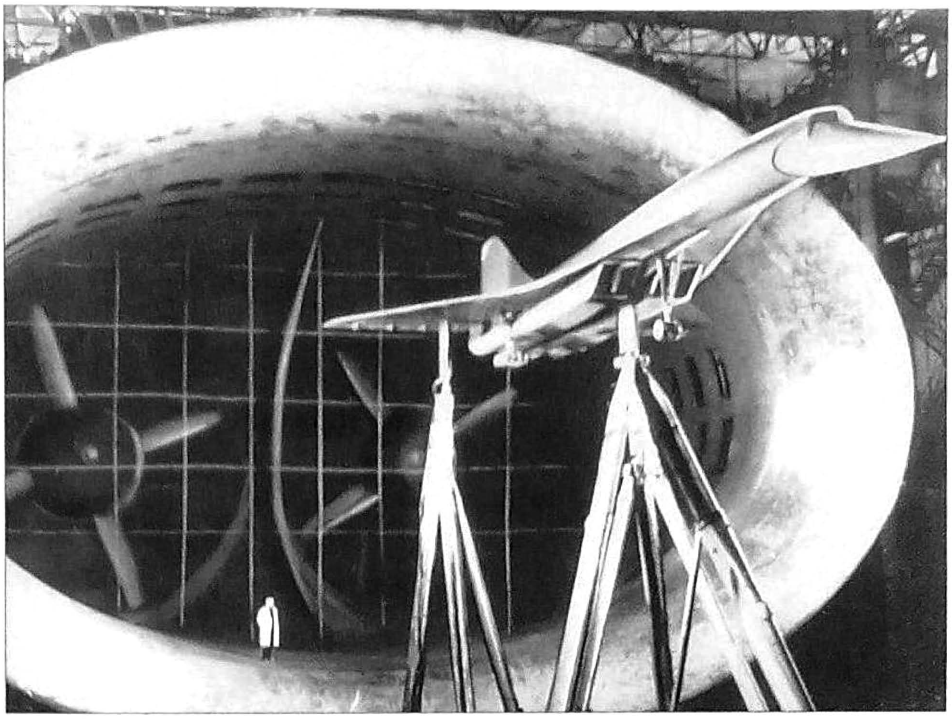


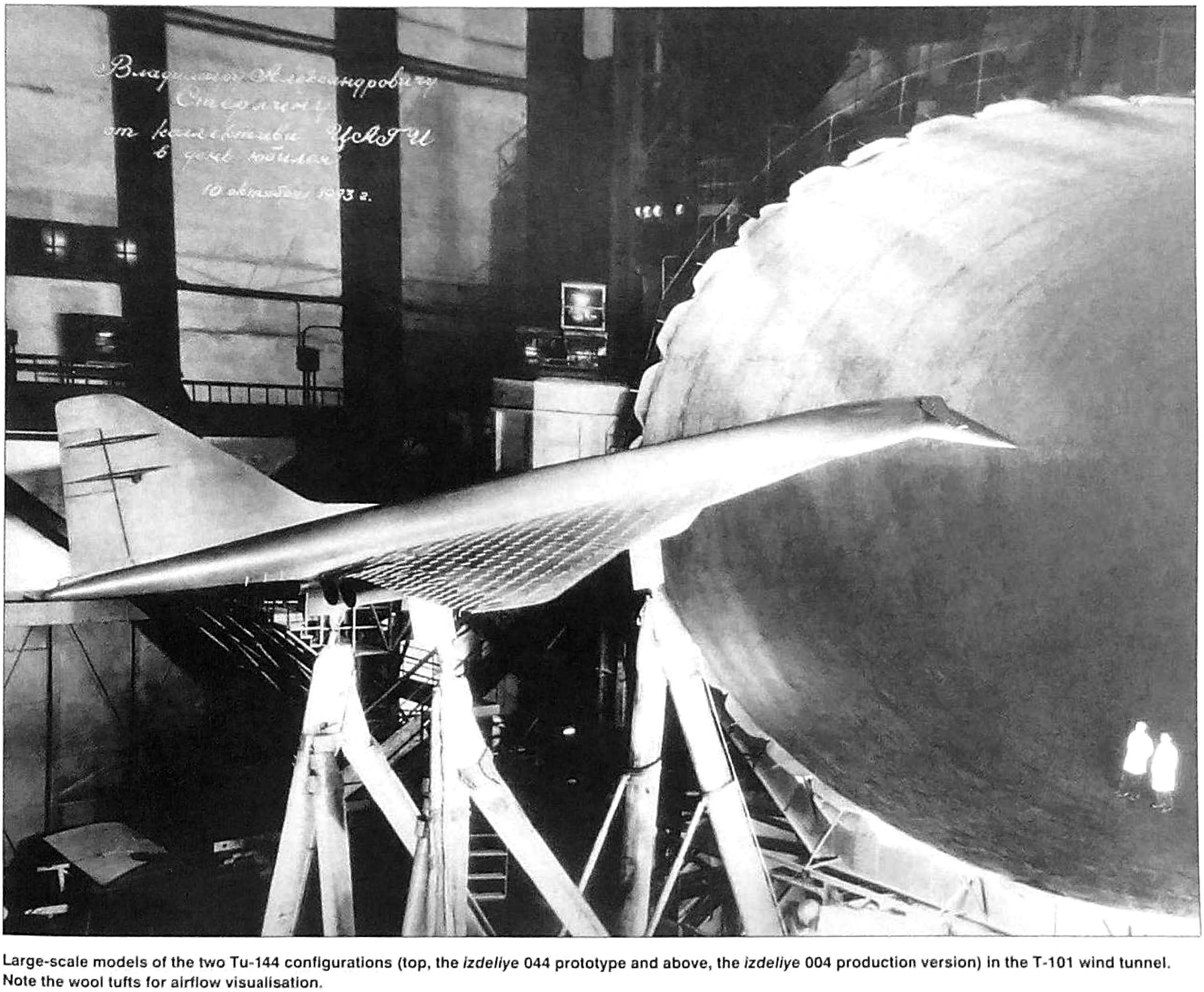
A model of the production-standard Tu-144 in the TsAGI wind tunnel.

A comparison of the engines powering the two SSTs shows that the Concorde's Bristol (later Rolls-Royce) Olympus 593 afterburning turbofan was more refined and more fuel-efficient than the NK-144. The Soviet engine designers ran out of time before they had a chance to create a hushkitted, reverser-equipped version of the RD36-51 (known as *izdeliye* 61) having an SFC on a par with the Olympus; with two or three more years' time available, this engine could have flown on the Tu-144.

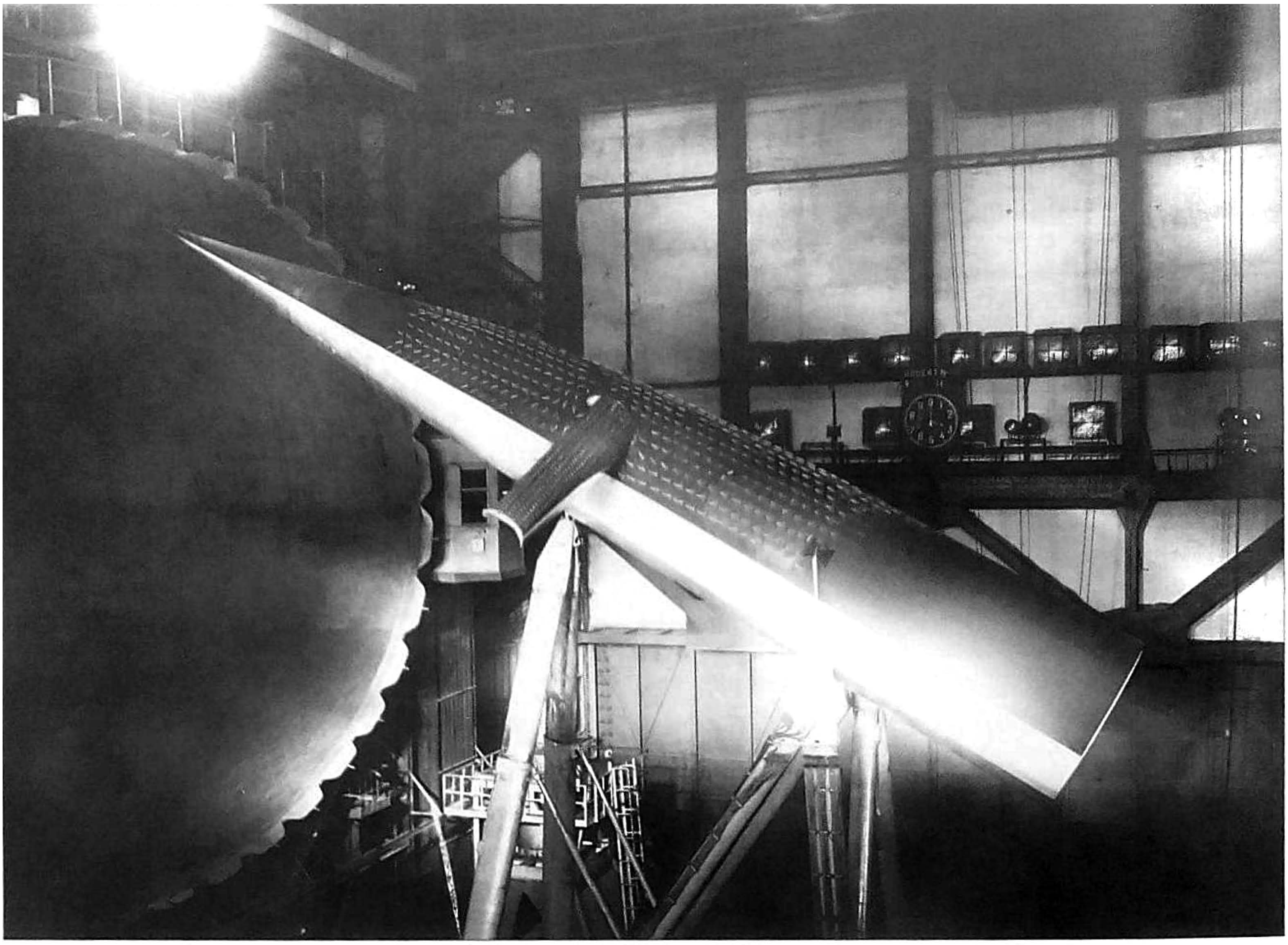
The Tu-144's air intakes offered a similar mass flow to those of the Concorde but had a lower pressure ratio. On the other hand, the Soviet aircraft's fuel tanks were better sealed against leaks and the Tu-144's fuel system was generally characterised by better fire safety.

The airframe design of an SST differs from that of a subsonic airliner primarily in the need to absorb the strong kinetic heating at supersonic speeds. The higher the cruise Mach number, the more severe this phenomenon





Large-scale models of the two Tu-144 configurations (top, the *izdeliye* 044 prototype and above, the *izdeliye* 004 production version) in the T-101 wind tunnel. Note the wool tufts for airflow visualisation.



A model of *izdeliye* 004's forward fuselage with the canards and their high-lift devices deployed in the T-101 wind tunnel; the model is again tufted. Note the extreme angle of attack at which the model is positioned.

becomes. This is why the Tu-144's designers opted for a cruising speed of 2.2; an aircraft designed for this speed could still utilise aluminium alloys as the primary structural material, which gave a considerable cost reduction as compared to titanium and increased the airframe's service life. Incidentally, the Concorde, too, was originally designed to cruise at Mach 2.2 but in the course of airline service the aircraft's cruising speed was limited to Mach 2.05.

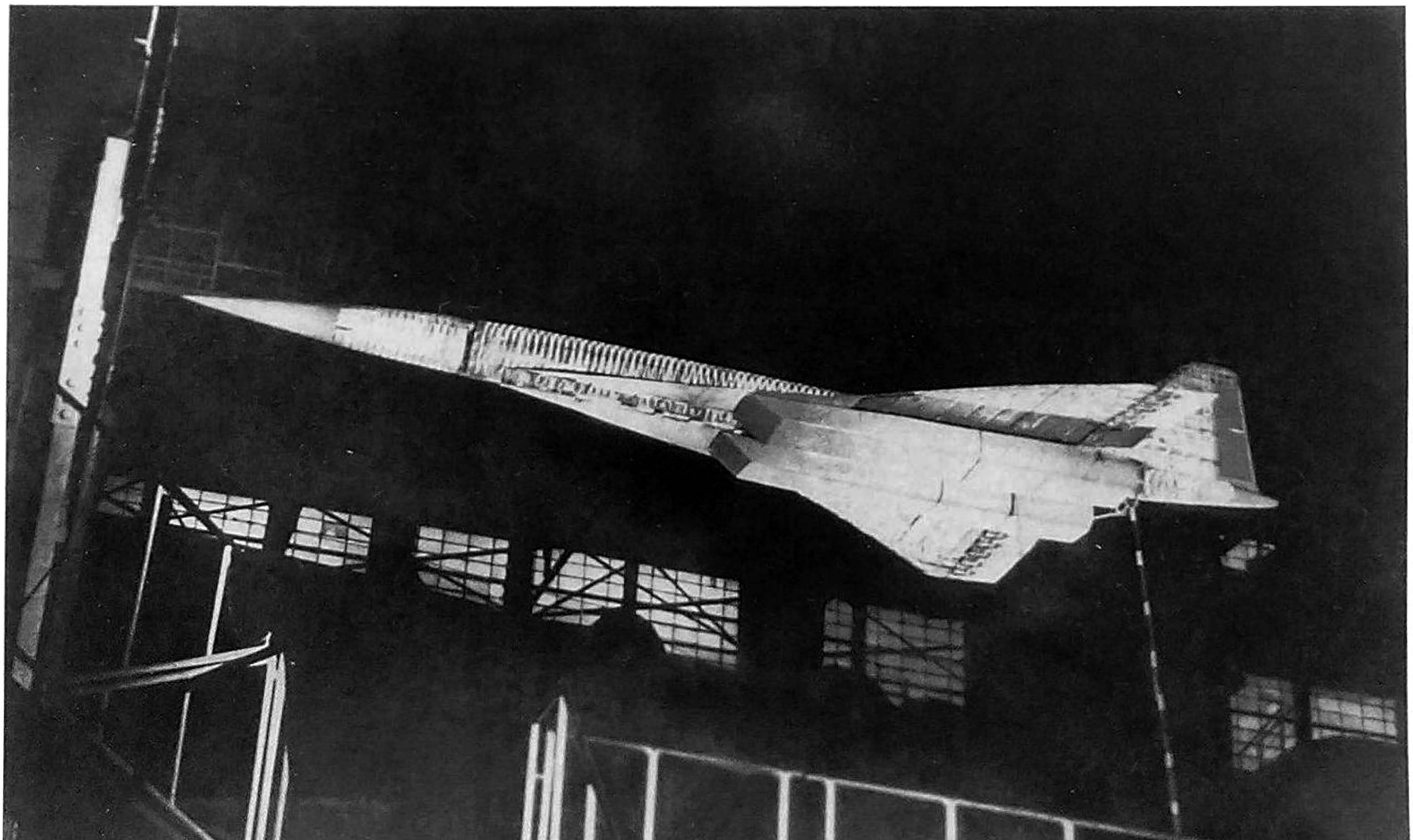
The kinetic heating dictates the choice of not only the SST's structural materials but also of the general arrangement, the flight trajectory and flight modes. Nearly 40 years ago the Tupolev OKB – first and foremost a small design team under V. A. Andreyev (currently the Tupolev PLC's Chief Designer for cryogenic aircraft) – came face to face with these problems for the first time. The task of determining the airframe structure's equilibrium temperatures (with due regard to the air conditioning/cooling system's operation and the thermal capacity of the fuel) was one of the toughest. Proceeding from the work done by various research institutes, the OKB developed calculation techniques and undertook

Basic performance of the engines powering the first-generation SSTs

	Kuznetsov NK-144	Kuznetsov NK-144A	Kolesov RD36-51A	Rolls-Royce Olympus 593/ Olympus 610
Application	Tu-144 prototype (*izdeliye* 044)	Tu-144 production (*izdeliye* 004)	Tu-144D (*izdeliye* 004D)	Concorde
Take-off thrust, kgp (lbst)	17,500 (38,580)	20,000 (49,020)	20,000 (49,020)	14,900/17,260 (32,850/38,050)
Maximum cruise thrust, kgp (lbst)	5,000 (11,020)	5,000 (11,020) *	5,000 (11,020) * †	4,550 (10,030)
SFC at maximum cruise thrust, kg/kgp·hr (lb/lbst·hr)	1.58 ‡	1.81 ‡	1.22	1.19)
Dry weight, kg (lb)	3,540 (7,800)	3,540 (7,800)	3,900 (8,600)	4,685 (10,330)
Service life, hours	n.a.	500	300	n.a.

* At 18,000 m (59,055 ft) and Mach 2.2
† Also quoted as 4,600 kgp (10,140 lbst)
‡ At 16,100 m (59,055 ft) and Mach 2.0

Above: A 'doctored' picture showing Tupolev OKB engineer A. L. Pookohov in a 'split state of mind' over a structurally similar model of the Tu-144 (*izdeliye* 004).



The structurally similar model suspended for testing.

experiments making it possible to calculate the Tu-144's equilibrium and gradient temperatures (that is, temperatures rising and falling during the climb to/descent from cruise altitude); these figures tallied well with the results obtained during actual flight tests.

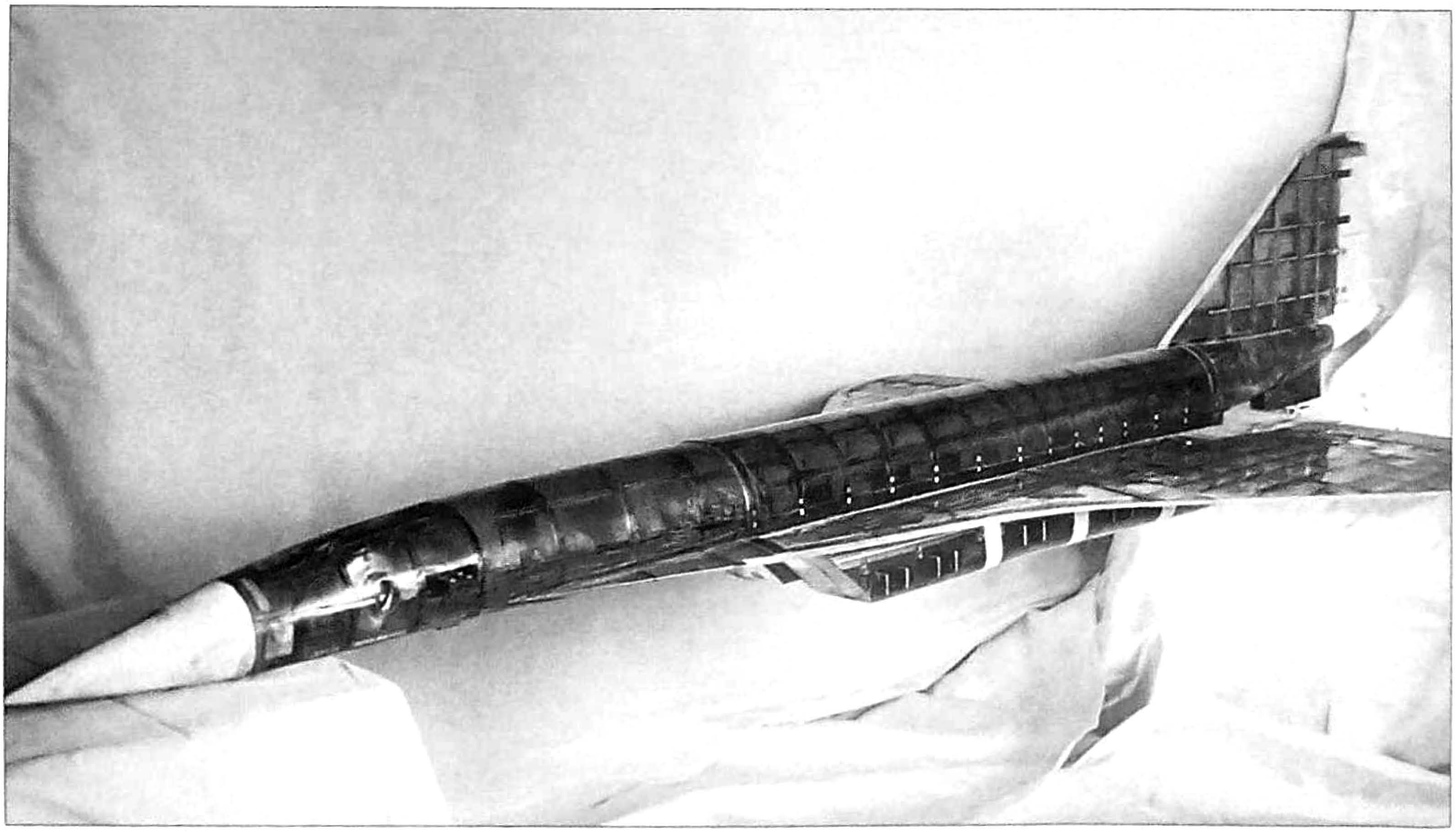
Protecting the rear fuselage from the hot jet exhaust turned out to be another major challenge. It transpired that nobody in the Soviet Union had taken on this issue before; there had been no need to, as the fact jets developed by other design bureaux (Pavel O. Sukhoi's OKB-51, Mikoyan's OKB-155 and others) had the engine nozzle(s) positioned either at the aft extremity of the fuselage or well away from the fuselage sides. Hence there was no ready-made solution. The problem was aggravated by the fact that in sustained supersonic cruise the skin temperature of the primary structure (including the hottest areas of the airframe) came close to the limit beyond which aluminium alloys started melting, compromising structural integrity. The jet efflux issue was not critical for the Concorde whose engine nacelles were placed much farther from the fuselage. At the Mach 2.35 cruising speed originally envisaged, the Tu-144's skin temperature was expected to reach 140°C (284°F). However, the decision to use powerful afterburning turbofans with large-diameter nozzles led to an increase in the speed and temperature of the efflux (the core of the jet could get as hot as 1,500°C/2,732°F) and increased thermal loads and stresses on the rear fuselage. The location of all four engines in a common nacelle on the prototype only made the problem worse.

The specialists of the Tupolev OKB and other R&D establishments began a large-scale theoretical and practical research effort to explore the exhaust jet dynamics and the interaction of the jet efflux with the airframe. Test flights of the Tu-144 prototype (*izdeliye* 044) revealed severe overheating of the entire rear fuselage structure aft of the engine nozzles; the maximum recorded temperatures ranged from 360° to 450°C (680-842°F), which was inadmissible even for a titanium structure because of the high structural loads involved. To remedy this, a heat shield consisting of a titanium sheet skin and a basalt fibre filler was fitted to the rear fuselage; special evaporative-action radiators were installed inside the rear fuselage to cool the structural members. As a further measure aimed at reducing the thermal loads, the Tu-144's cruising speed was later limited to Mach 2.2.

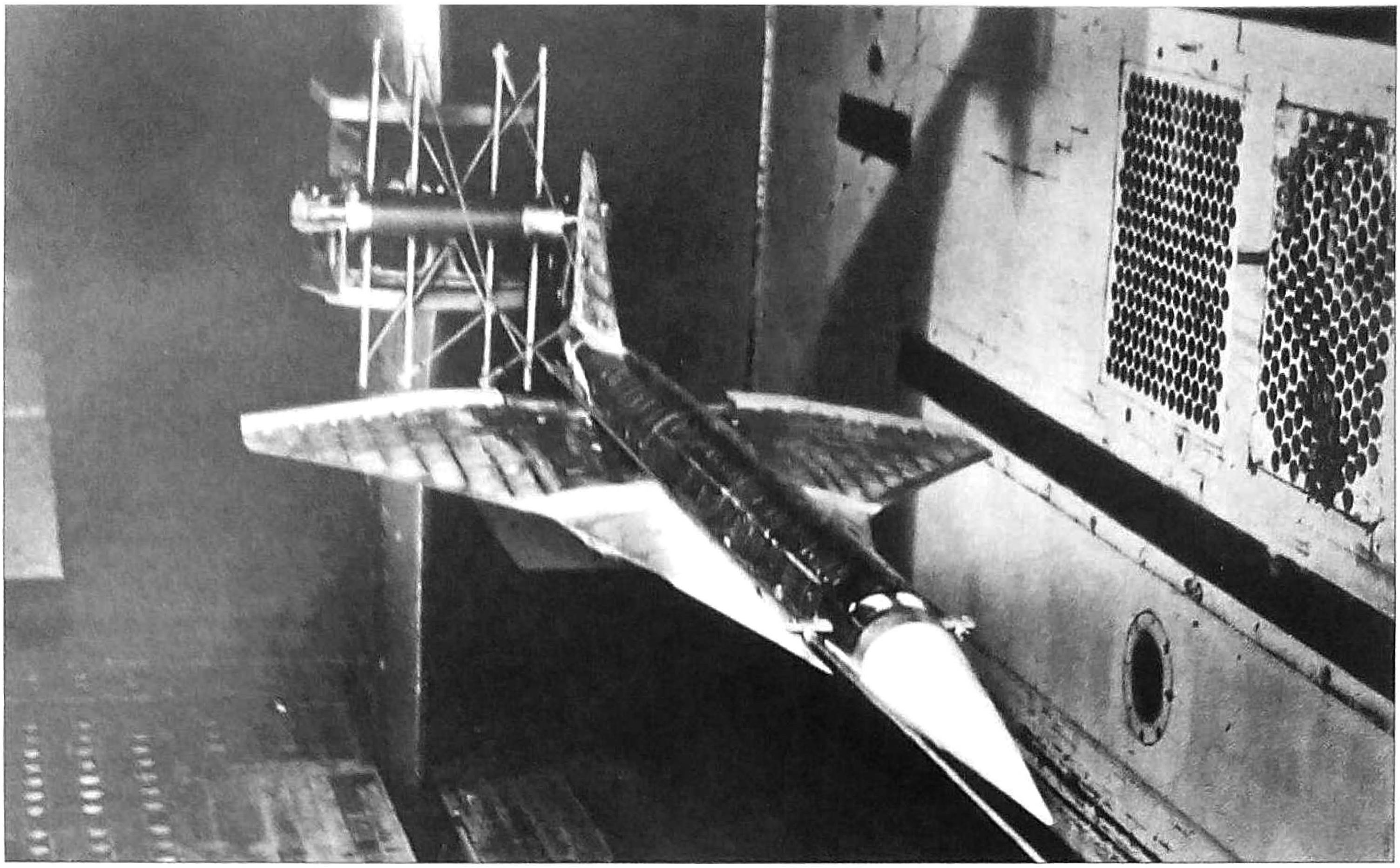
On the radically redesigned production Tu-144 (*izdeliye* 004) the common engine nacelle gave place to two separate nacelles with the pairs of engines moved outwards to prevent the exhaust from impinging on the rear fuselage skin. Still, the overheating persisted, albeit the problem was alleviated somewhat, and the production model retained the heat shield.

Even now, after all these years, the Tu-144 commands respect with its impressive and refined aerodynamic forms, clever design features and unconventional approaches to new design problems. It is often alleged that the Tu-144 was created entirely by up-and-coming young specialists. Nothing could be farther from the truth; with all due credit to young innovators, you cannot beat experience. As was his wont, Andrey N. Tupolev personally picked the people who would handle the most complex and high-priority tasks, trying to find that optimum combination of young talent and maturity that had always assured success in the past. The choice of the general arrangement and aerodynamic layout, the placement of the basic systems inside the airframe and other highly complex issues were efficiently handled by the PD section under Valentin I. Bliznyuk. At the early design stage, work in the main areas of design was headed by A. L. Pookhov, Ye. I. Kholopov, V. I. Kozlovskiy, V. D. Vostroknootov, V. I. Korneyev and Ye. I. Schekhterman. The airframe was designed under the supervision of I. F. Nezval' and B. A. Gantsevskiy, old hands with a wealth of experience.

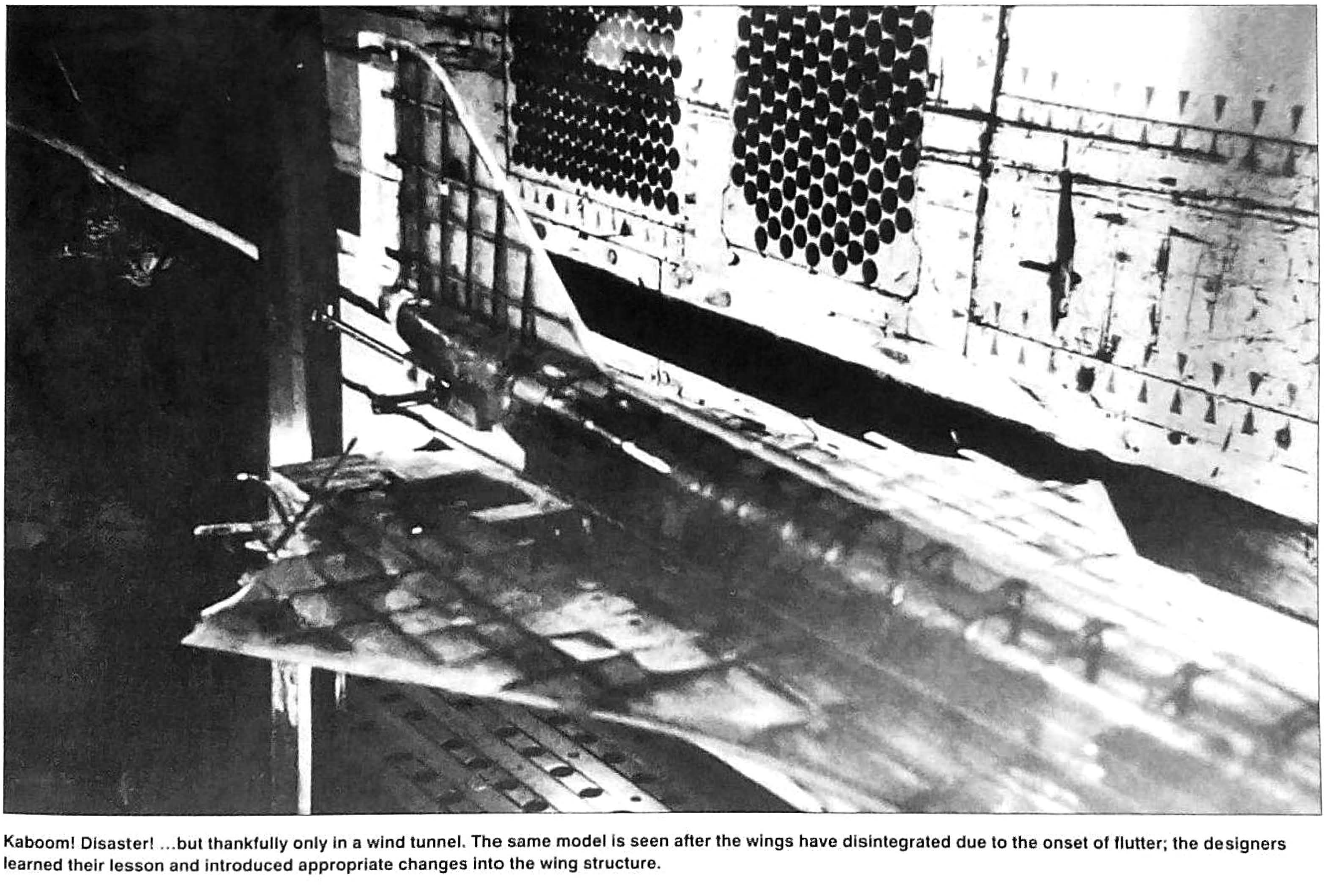
As was customary at the Tupolev OKB, after the airframe had been divided into basic subassemblies these were worked on in parallel by separate design teams and sections. For instance, the landing gear was developed by a special department headed by Ya. A. Livshitz, a first-rate 'gear man' who had been responsible for the undercarriages of the Tu-16, Tu-95, Tu-22 and other Tupolev aircraft. Along with the head office in Moscow, some other branches of the Tupolev OKB (notably the one in Tomilino township south



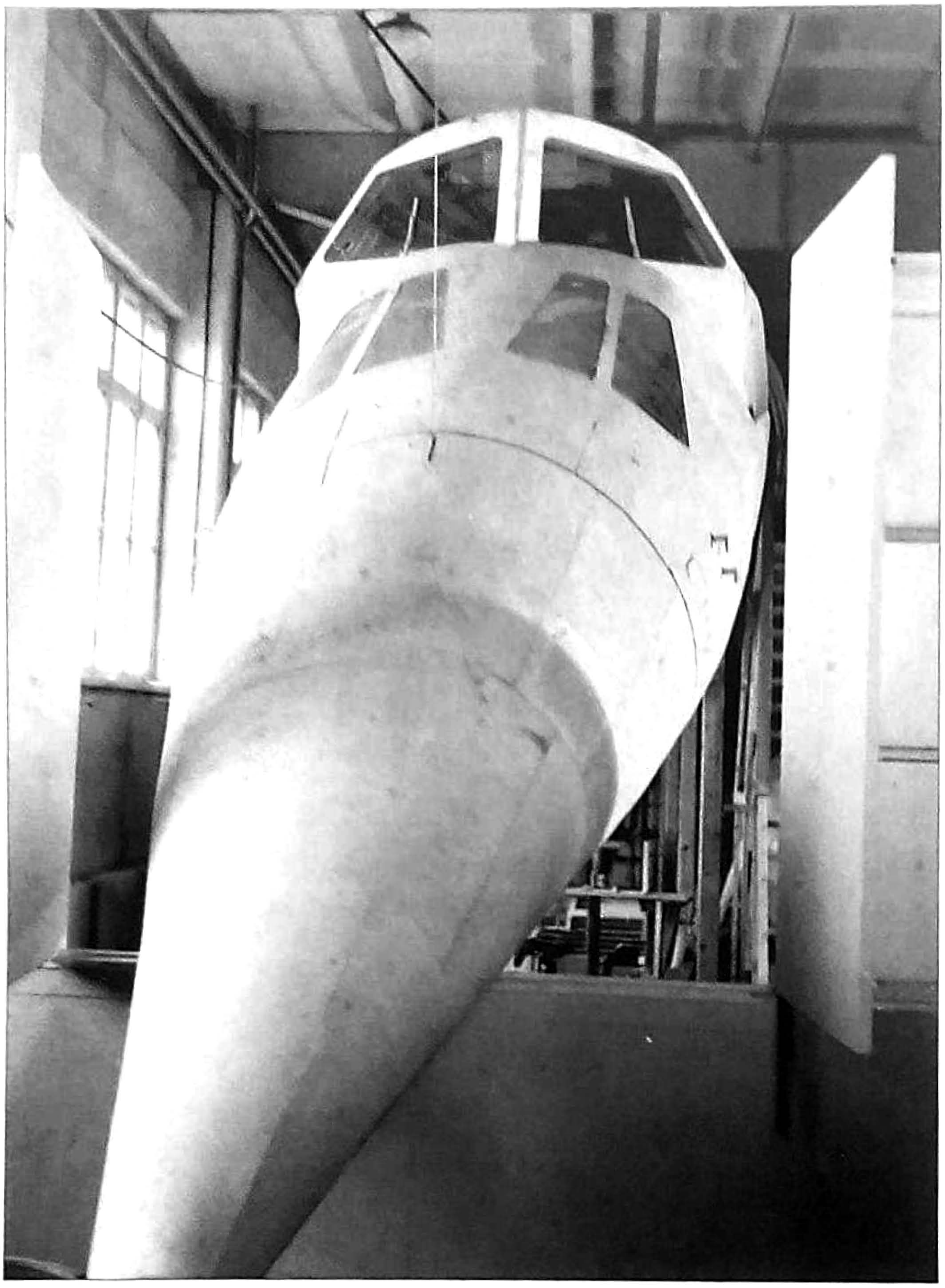
A scaled-strength model of the Tu-144 (*izdeliye* 044). Such models played an important part in the creation of the Tu-144.



Above: The scaled-strength model of the Tu-144 (*izdeliye* 044) in TsAGI's supersonic wind tunnel. Note the steel cables to which the model is attached.



Kaboom! Disaster! ...but thankfully only in a wind tunnel. The same model is seen after the wings have disintegrated due to the onset of flutter; the designers learned their lesson and introduced appropriate changes into the wing structure.



The drooped nose of the Tu-144's plywood mock-up in the mock-up shop of MMZ No.156 in Moscow.

of Moscow headed by V. Yu. Shaltuper) were involved in designing the airframe.

Structural strength issues assumed special importance when the Tu-144 was being designed. By the time the Tupolev OKB embarked on its first-generation SST programme it had accumulated a lot of practical experience in calculating the required strength of airframe structures. This stemmed from the development and service introduction of both commercial aircraft and military ones, including supersonic bombers and heavy interceptors. Still, the very nature of the SST programme demanded higher-than-usual reliability and hence a more exacting approach to structural strength.

At first this aspect of the design process was supervised by the Tupolev OKB's structural strength department chief A. R. Bonin; later, A. P. Gannushkin and V. V. Soolimenkov assumed this responsibility. TsAGI drew up a set of structural strength norms specifically for the Tu-144, and these were subsequently included into the Provisional Airworthiness Regulations for Supersonic Aircraft according to which the Tu-144 was certificated. Despite the OKB's long history, creating a supersonic airliner involved situations lying outside the designers' prior experience; this required the structural strength norms to be amended and new calculation techniques to be developed. TsAGI specialists (A. I. Makarevskiy, A. F. Selikhov, Yu. A. Stoochalkin *et al*) made a major contribution at this stage. At the Tupolev OKB, engineers B. L. Merkoolov, I. Ya. Borovaya, V. N. Perel'shtein, V. G. Yoodovich and I. A. Golovnya developed the calculation methods and calculated the Tu-144's actual design loads. Engineer F. A. Kocharian was actively involved in determining the strength norms and setting the loads to be applied to the static test airframe.

Transonic speeds were still largely unexplored at the time, and flight at transonic speeds called for the development of additional structural load calculation techniques. The Tu-144's peculiarities included its airframe loading at the moment of touchdown, during taxying and during the take-off and landing runs when the landing gear wheels ran over the imperfections of the runway surface (and the runways and taxiways at Soviet airfields were generally far from perfect). Because of the Tu-144's fairly flexible airframe, the jolts occurring in these conditions created sizeable structural loads applied to the fuselage; this wrought havoc with the aircraft's service life and had to be taken into account.

The designers spent a lot of effort on determining the airframe's structural design (the optimum location of the load-bearing elements) and optimising specific structural details. This work proceeded under the direction of V. P. Shoonayev, who went on to become the company's current structural strength department chief. The choice of the optimum structural design and the calculation of in-flight structural stresses and deformations called for calculation methods for which no software existed yet in the 1960s; therefore the possible structural design layouts were compared, using mathematical analysis and structurally similar models.

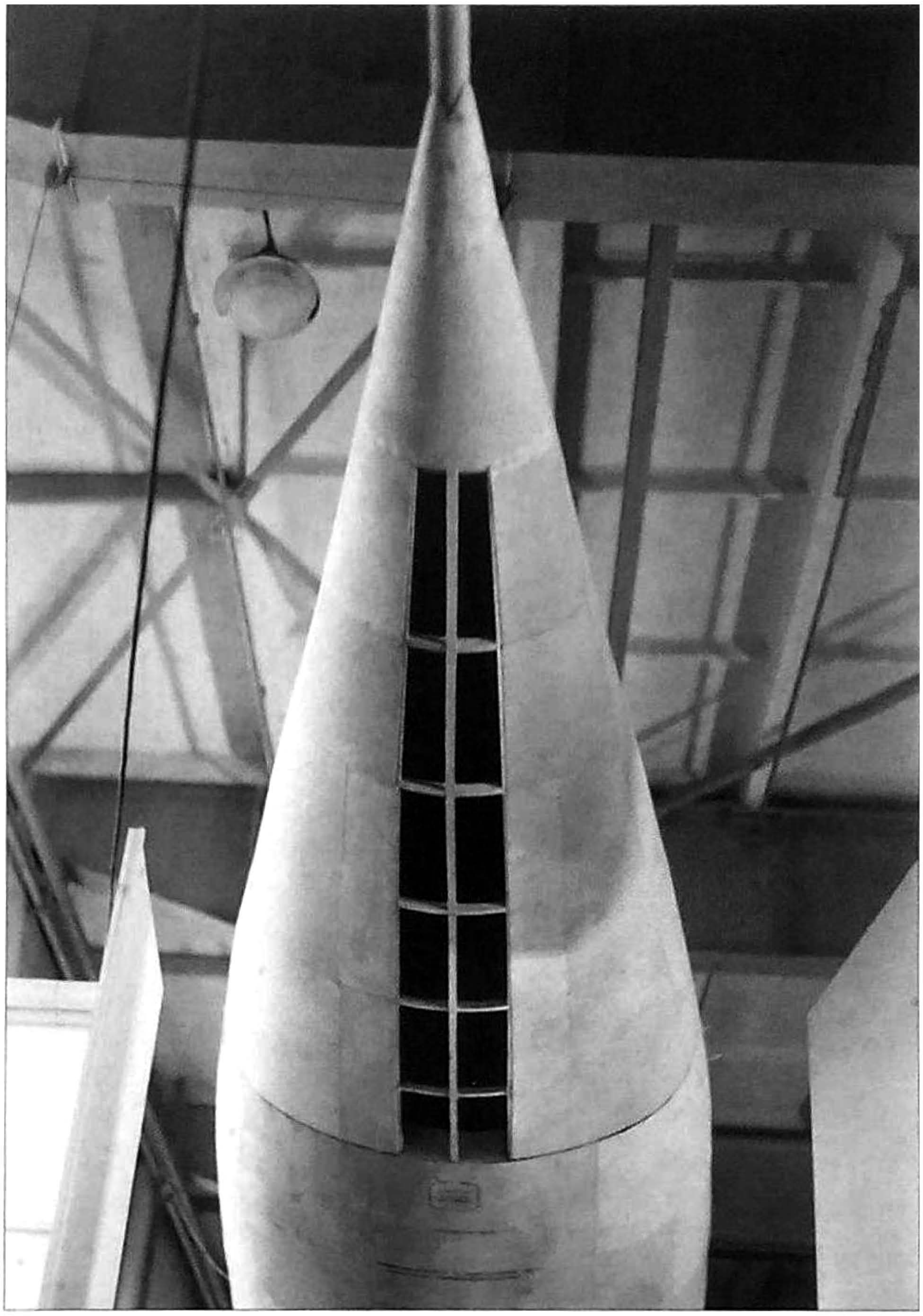
Initially a model of the M-50 bomber obtained from the defunct Myasishchev OKB was used for these experiments. Later the OKB designed and built several structurally similar models of the Tu-144 made of glassfibre and a metal model to 1/3rd scale. A lot of research on structural stress was done using static test articles. It should be noted that the use of structurally similar and scaled-strength models became a mandatory part of the Tupolev OKB's working practice for many years after the Tu-144 programme. Later, that era's only computerised method of calculating structural strength became available in the form of a programme designed by Yuriy Ye. Iliyenko; actually this software was designed for aeroelasticity calculations but, as a bonus, could also be used to determine structural stress. This, so to say, was the pebble that started the avalanche; from then on the Tupolev OKB began actively exploring computerised structural strength calculation methods, an effort that culminated in the development of the powerful Diana multifunction computer system under the supervision of V. L. Glezer and A. V. Stasevich.

Noteworthy research was done to explore thermal loads, thermal stresses and their effect on the airframe's functioning (this included not only structural strength but also metal creep and durability). This work performed together with TsAGI's Research Section No.3 (NIO-3) was directed by I. B. Ghinko and A. A. Kozlov.

As a Russian saying goes, 'new things are thoroughly forgotten old ones'. To stop thermal expansion/contraction from causing structural deformation impairing the airframe's functioning, the designers had to resort to using girder-type beams and corrugated sheets, just like in the early days of aviation. These were used for the wing spars and rib webs.

A production-standard Tu-144 airframe (construction number 01-3 – that is, Batch 01, third and final aircraft in the batch) was tested to destruction at TsAGI. These tests, and the subsequent fatigue tests of another production airframe (c/n 05-3) performed by the Siberian Aviation Research Institute (SibNIA – *Sibeerskiy naoochno-issledovatel'skiy institoot aviahtsii*) in Novosibirsk, fully confirmed the validity of the design features used. Large-scale fatigue tests were performed by TsAGI and SibNIA by means of purpose-built test rigs as part of the Tu-144's certification trials. During the 'hot' fatigue tests, in addition to the usual structural loads and pressurisation of the cabin by compressed air, the entire airframe was heated and cooled from outside by a stream of air to simulate the kinetic heating/cooling cycles in actual flight. This turned out to be a major logistical challenge; SibNIA had to build a special transformer station for the purpose of supplying the hot air blower's electric heaters with power and build a special railroad spur so that liquid nitrogen for the system's cooling plant could be delivered.

Fighting the dangerous manifestations of aeroelasticity (flutter and control surface reversal) is a difficult enough task even when designing a conventional subsonic aircraft; with a supersonic airliner, the task becomes monstrous. It is tackled by means of scaled-strength models tested in wind tunnels. Such a model of the Tu-144 for flutter tests was created by the OKB, using a software package developed by TsAGI. Calculations made with the help of this model helped to determine the aircraft's own oscillation frequencies. Eventually several dozen structurally similar scaled-strength models made of carbonfibre reinforced plastic or celluloid were manufactured for wind tunnel tests. The engineers' task was further complicated by the need to simulate differing fuel loads on these models.

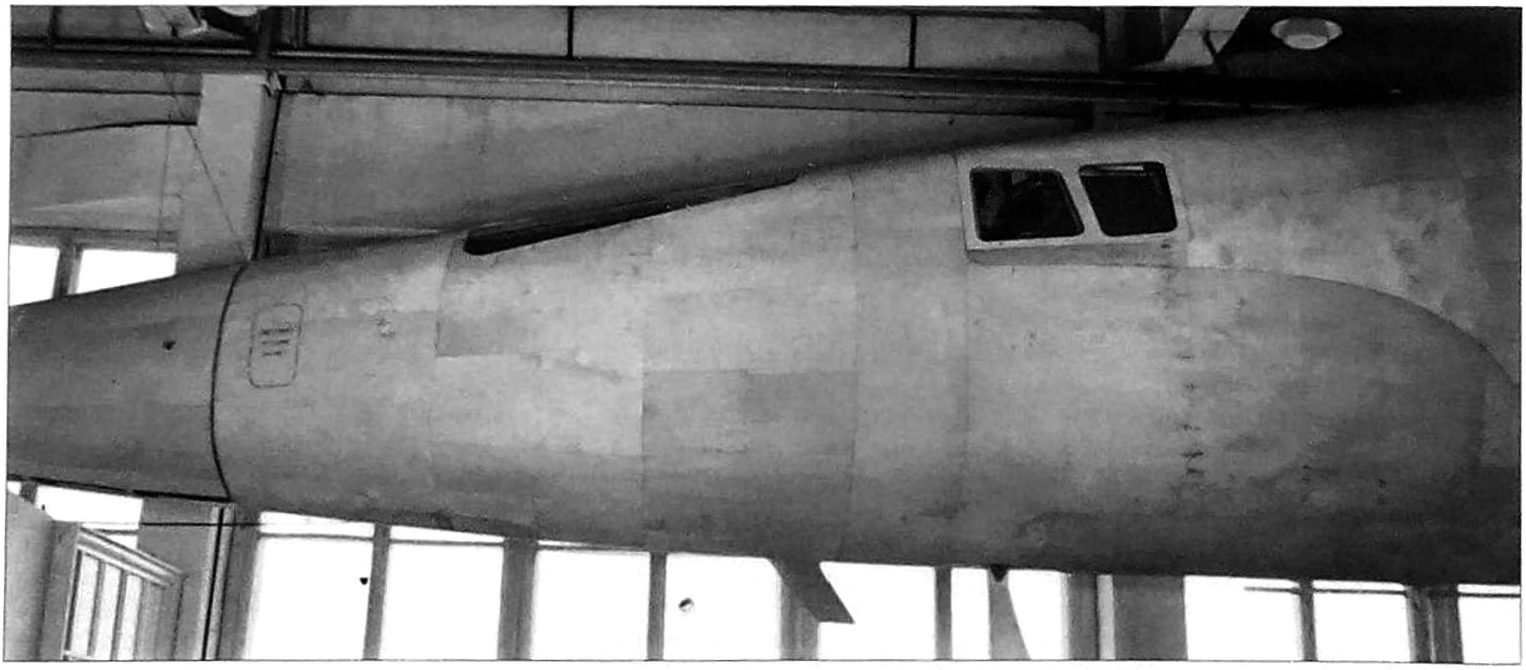


A look up at the underside of the still unfinished mock-up's nose section. Ventral maintenance hatches can be discerned aft of the nose visor/forward fuselage joint.

Even before the Tu-144 had been developed, the structural strength norms had contained clauses about aeroelastic stability; these meant that under no circumstances should the interaction between an elastic airframe and the aircraft's automatic flight control system result in oscillations. However, it was the Tu-144 that became the first aircraft on which the methods of dealing with such oscillations were tried out in earnest.

Flight tests and in-flight measurements give the final verdict as to whether the anticipated aerodynamic load figures for various flight modes (obtained by calculation and in wind tunnel tests) are correct or not. With the Tu-144, the technique lay in measuring the strain fields on the wings' upper and lower skins and measuring the strain levels on the spar webs and the ribs. The wing deformation caused by structural weight and the fuel load inside the wings and aerodynamic loads had to be taken into account when designing the optimum wing shape (planform, camber, incidence and so on) in order to achieve the maximum possible lift/drag ratio. This was done at the project stage – the anticipated deformation had been calculated and 'designed into' the wings. When tests began, the need arose to compare the estimated deformation with the real picture; this was done in a novel way by placing photo cameras operating in accordance with a certain algorithm at the cabin windows. This new and exciting job was performed by A. L. Pookhov and I. K. Kulikov, and the real-life deformation matched the estimates exactly.

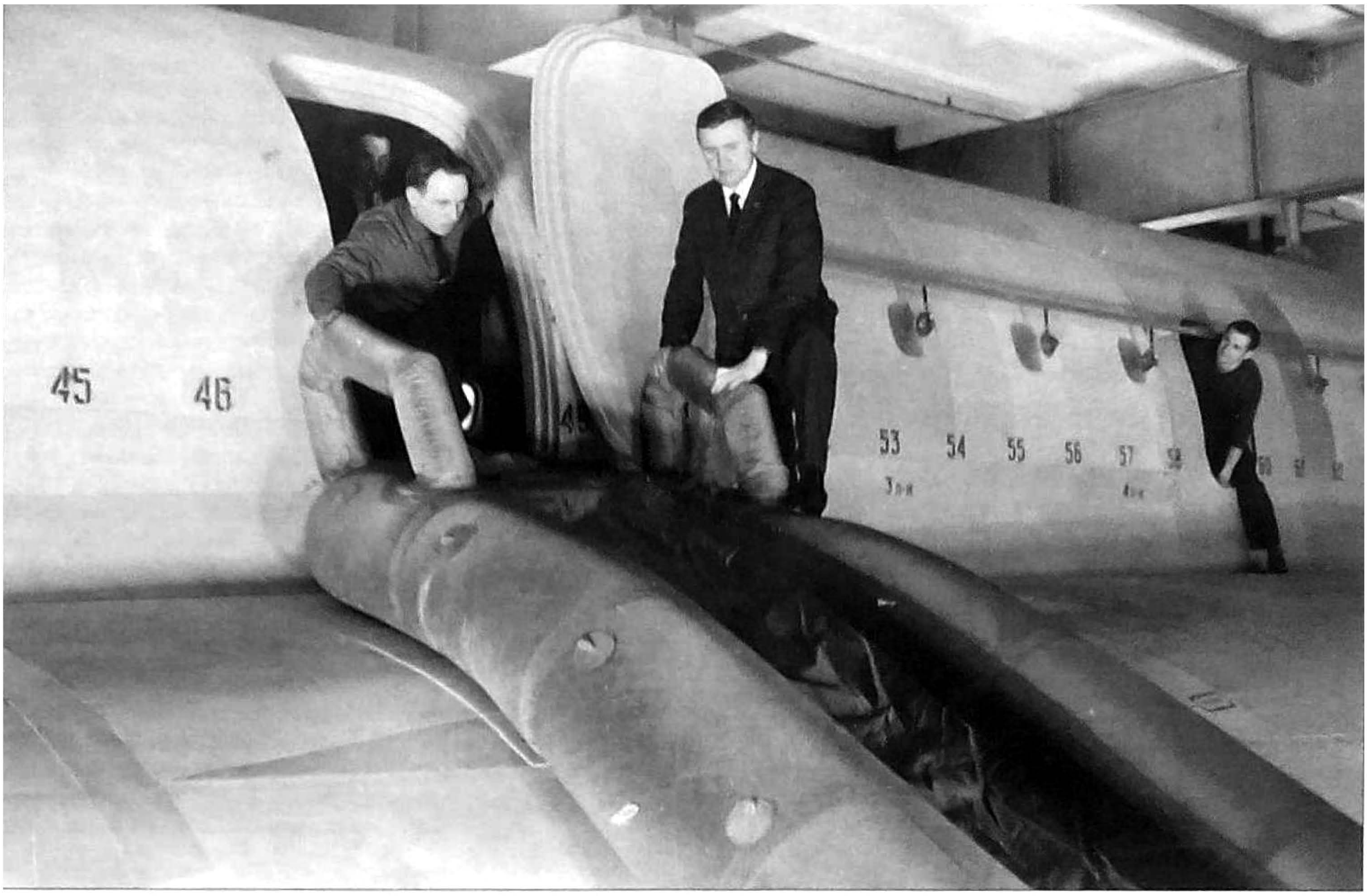
Above: The mock-up's forward fuselage with the nose drooped for take-off and landing, exposing the V-shaped windshield.
Below: When raised into cruise configuration the nose blends completely into the fuselage contour. The forward view becomes rather limited.



Development of a supersonic airliner designed for sustained Mach 2 cruise necessitated an unconventional approach to many design aspects. This was due primarily to the strong kinetic heating; in cruise flight the boundary layer temperature reached 150-180°C (302-356°F), the aircraft's skin heating up to 110-130°C (230-266°F). As a result, the requirements applied to the air conditioning system were totally different; whereas the ACS of a typical subsonic airliner was required to heat the cabins with warm air, delivering 10,000-20,000 kcal/hr, an SST's air conditioning system was required to cool the cabins, delivering cold at a rate of 60,000-80,000 kcal/hr! Without it, everyone and everything inside the fuselage would be literally cooked.

The Tu-144's ACS developed under the supervision of G. A. Sterlin in close co-operation with NPO *Naooka* ('Science' Research & Production Association; NPO = *naoochno-proizvodstvennoye obyedineniye*) incorporated many unusual features, and the result was truly impressive. Far from being just a system providing creature comforts for the passengers, the ACS turned into a life support system for the occupants and a system ensuring the normal functioning of the aircraft's avionics in supersonic cruise. Development and testing of the Tu-144's air conditioning system took several years of research and development work.

The most noteworthy part of the system was the so-called dynamic heat insulation – a multi-layer structure consisting of an outer glassfibre layer (the static layer) and porous inner panels with air ducts. In the cabins this 'sandwich' was concealed from view by porous wall liner panels. Cabin pressurisation air was sucked from the interior and forced between the layers to protect the cabin against the kinetic heating in cruise flight. As



The full-scale mock-up featured functioning inflatable escape slides at the doors. Note the fuselage frame numbers marked on the fuselage (plus wing spar numbers – 3 at frame 53 and 4 at frame 57) and the lamps shining through the cabin windows. The doors of the actual aircraft did not swing open in this fashion.

compared to conventional 'passive' heat insulation with heat/soundproofing mats, the active heat insulation system offered several advantages. Agreeable temperatures were maintained throughout the flight envelope in pressurised and unpressurised sections of the fuselage alike (the latter were cooled by air spilled from the cabin); the heat penetrating the insulating layer was reduced by a factor of 2.0-2.5, allowing the capacity of the air conditioning system to be reduced, and the equipment in the unpressurised bays was adequately cooled.

The dynamic heat insulation was put through its paces in 1966 or 1967, using the appropriately modified fuselage of a Tu-134 *sans suffixe* (probably the static test airframe) converted into a test rig. The fuselage with a metal fairing replacing the nose glazing was placed in a chamber with foam plastic insulated walls into which hot air was blown to heat the outer skin to 160°C (320°F). The other ACS components were installed in a special hyperbaric chamber next door imitating flight at up to 20,000 m (65,620 ft) and connected to the fuselage by ducts. The dynamic heat insulation worked perfectly.

Incidentally, the other ACS components (such as the cooling turbines) were also unique, as the system had a variable cycle, heating the cabin on the ground (in the cold season) and at subsonic speeds and cooling it in supersonic cruise and on the ground (in the summer season). Consider that the temperature of the engine bleed air used for pressurisation/air conditioning could reach 530-570°C (986-1,060°F). Most of the air conditioning system's features had no equivalents in indigenous or foreign aircraft design practice and were duly patented.

The tailless-delta layout with low aspect ratio wings offered optimum performance in sustained supersonic cruise but was characterised by instability in a number of other flight modes (poor pitch and roll stability and airspeed fluctuations during the landing approach). Besides, the SST had higher unstick and approach speeds as compared to subsonic airliners. All of this necessitated a huge amount of R&D work on the Tu-144's control system, including the ABSU-144 automatic flight control system (AFCS). For starters, the electronic components of the system were verified on a Tu-104 airliner converted into an avionics testbed.

The new nature of the tasks to be solved led the OKB to use new design features. In particular, the AFCS had to remain activated throughout the flight, providing the required stability and handling. Hence each of the control channels was made quadruply redundant for maximum reliability and quick-action electro-hydraulic control surface actuators were used. To overcome the approach speed problem the AFCS included an autothrottle stabilising the airspeed during final approach. To reduce the approach speed the production Tu-144 was equipped with the above-mentioned retractable canard foreplanes allowing the elevons to be used as flaps, increasing lift. This feature was a world 'first'.

The Tu-144's control system offered easy and comfortable control thanks to the automated features maintaining constant (and good) control characteristics in all flight modes and thanks to the G load/AOA limiter. The multiple redundancy of the control system hydraulics made sure that the flight envelope was unaffected by the failure of one hydraulic system, certain limits being imposed for flight safety reasons if any two systems failed.

The ABSU-144 was designed from scratch and enabled the following automatic control modes:

• automatic programmed course selection, using input from the navigation suite;

• automatic ICAO Cat II landing approach (decision altitude 30 m/100 ft, horizontal visibility 400 m/1,300 ft) and, if required, automatic go-around;

• automatic Mach number stabilisation in cruise flight;

• automatic stabilisation of barometric altitude, pitch, heading and desired track;

• alteration of pitch, heading, desired track and execution of co-ordinated turns;

• automatic stabilisation and alteration of the indicated airspeed by adjusting the engine thrust;

• presentation of flight and navigation data on the flight director and the artificial horizon.

The ABSU-144 was an integrated suite comprising the SAU-144 automatic control system (*sistema avtomaticheskovo oopravleniya*), the STU-75 approach/landing system (*sistema trayektornovo oopravleniya*), the SUU-144 stability and control system (*sistema oostoychivosti i oopravlyayemosti*), the AT-6 autothrottle (*avtomaht tyaghi*) and the SVK-144 built-in test equipment (*sistema vstroyennovo kontrolya*). All systems had back-up features activated automatically in the event of a failure.

Major changes had to be made to the hydraulic system as compared to subsonic aircraft, as this crucial system catered for many other systems – first and foremost the control system. Thus, in order to maximise the efficiency of the hydraulic actuators while keeping their size and weight to a minimum the OKB had to commission hydraulic pumps and drives with a working pressure of 200 bars capable of working at temperatures up to 170-200°C (338-392°F). The following other novel features were also introduced into the hydraulic system:

• a combined hydraulic reservoir pressurisation system using compressed nitrogen bottles as the primary source and the air conditioning system as a back-up. This operating algorithm significantly improved the pressurisation system's reliability, precluding the ingestion of dust and moisture into the hydraulic system from outside the aircraft;

• a hydraulic fluid cooling system featuring a fuel/hydraulic heat exchanger and thermostatic valves (the latter allow the fluid to reach the required operating temperature quickly at low ambient temperatures and maintain the correct temperature in all flight modes);

• all-new resonance-type pulsation dampers featuring no movable parts, which makes for high efficiency, reliability and a long service life;

• all-new hydraulic line tension/deformation compensators;

• an emergency turbine pump unit allowing all hydraulic equipment to operate even with all four engines inoperative;

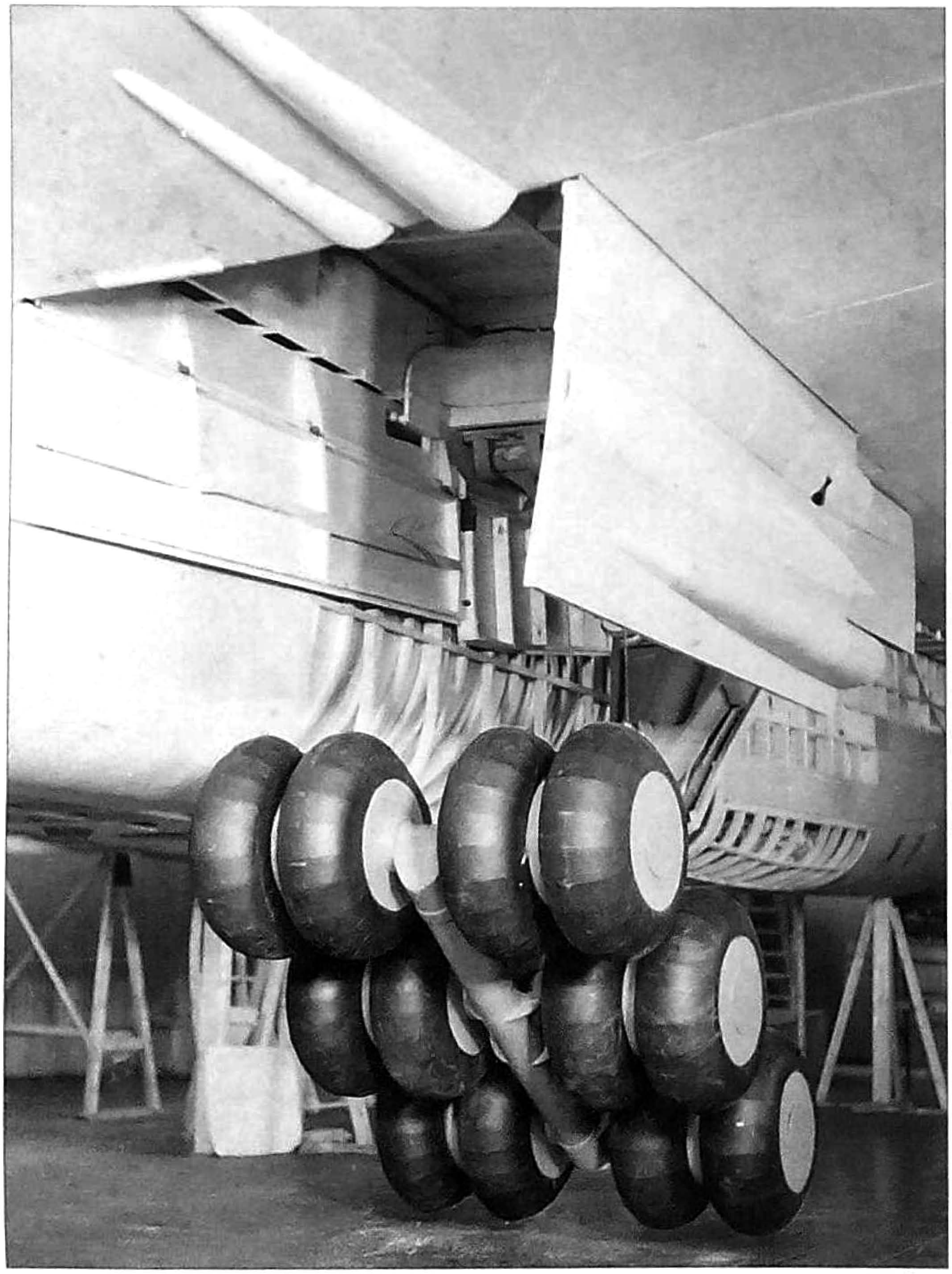
• a hydraulic pump monitoring system featuring a cross-feed valve, a flow meter and a pressure gauge with a remote sensor;

• a system maintaining pressurisation of a hydraulic reservoir shared by two hydraulic systems if one of them is ruptured;

• combined hydraulic modules reducing the number of modules and piping connections.

The hydraulic system operated the control surface actuators, landing gear actuators, wheel brakes and the flow control ramps in the engine air intakes. Hence special attention was paid to reliability; the system comprised four completely separate subsystems, the key hydraulic drives being powered by two subsystems each.

The Tu-144 programme called for the development of a new generation of avionics and electric equipment, which were computerised to a considerable degree. The complexity of the navigation suite, on which flight safety depended, was increased perceptibly, too. Many of the electric and electronic equipment items were unique to supersonic aircraft. The Tu-144's avionics and electric equipment incorporated the latest know-how developed by numerous research and production enterprises. These included the Moscow Institute of Electronics (MIREA), LNPO Elektroavtomatika ('Automatic Electric Devices'; LNPO = *Leningrahdskoye naoochno-proizvodstvennoye obyedineniye* – Leningrad Scientific & Production Association), the Ramenskoye Instrument Design Bureau (RPKB – *Ramenskoye priborno-konstrooktorskoye byuro*), the *Rodina* (Mother-

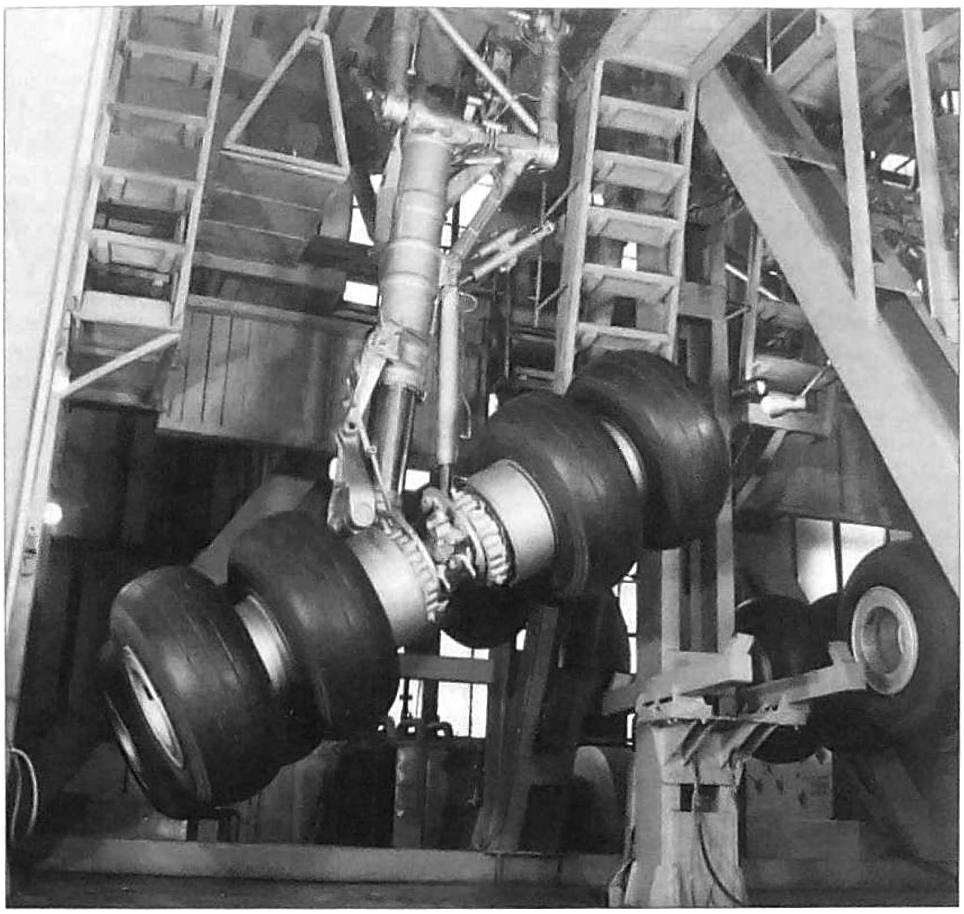


The mock-up had a fully functional landing gear. The 12-wheel bogie is readily apparent but the 'knee-action' strut is not.

land) design bureau, the Naooka and *Dzerzhinets* (Dzerzhinskiy's comrade-in-arms) manufacturing plants, the *Yakor'* (Anchor), *Rubin* (Ruby) and *Kristall* (Crystal) design bureaux, the *Kommunar* (Commune worker) Production Association, MKB *Voskhod* ('Sunrise' Moscow Design Bureau), MMZ *Zvezda* (Star) and others.

The electric systems of the day utilising generators with pneumatic/mechanical drives were unsuitable for an SST as far as both power output and electric current parameters were concerned. Therefore the Tupolev OKB chose to use a three-phase stable-frequency alternating current system featuring 60-kVA generators driven via hydromechanical constant-speed drives as the primary electric system. No Soviet aircraft had used such a system before, and Soviet technology was lagging far behind the Western world in this respect, so the OKB was breaking new ground once again.

Again, a large amount of research had to be undertaken and new standards and regulations developed. A branch of LII teamed up with the Dzerzhinets and Rubin design bureaux (responsible for the generators and the CSDs respectively) and contributed its own research, allowing a state-of-the-art 200/115 V/400 Hz three-phase stable-frequency AC



Top: The landing gear of the production model undergoing tests on a test rig at the Tupolev OKB.
Above: a production Tu-144 undergoing landing gear retraction checks at the Voronezh aircraft factory.

electric system with a nominal output of 240 kVA to be put into production. The increased operating temperatures throughout the airframe made it imperative to develop and put into production a new generation of heat-resistant electric wires.

The Tu-144 was the first Soviet aircraft to make large-scale use of computers and processors in various systems, and it is a well-known fact that processors can be damaged by voltage spikes or power failures. Hence the electric system included power supply monitoring devices which automatically (and promptly) switched the processor to a different power distribution bus if the current one failed. The need to ensure a safe landing in the event of an electrics failure in supersonic cruise led the designers to rethink the electric system structure completely, separating the AC and DC subsystems by function. This structure later became universally accepted and is used on all present-day aircraft.

Long-range supersonic flight necessitated development of a new-generation navigation suite as well. This suite, which, like the engine, was designated NK-144 (in this case the NK stood for *navigatsi**on**nyy **kom**pleks*, not Nikolay Kuznetsov), was intended for flights along designated airways and outside them, in any geographical conditions and in any season, day or night. The navigation suite enabled the following modes:

- non-stop automatic computation and indication of the aircraft's current co-ordinates and heading in the geographical and orthodromic co-ordinate systems;
- automatic and manual course and co-ordinate correction;
- computation and indication of the estimated time of arrival (ETA) and the minimum distance remaining to the destination point and any of other pre-programmed points;
- computation and indication of the current flight altitude and audiovisual warning of departure from the designated flight level;
- computation and indication of the pitch and roll angles, current magnetic and gyroscopic headings;
- computation and indication of the indicated airspeed (IAS), true airspeed (TAS), Mach number and outside air temperature and entering these data into the AFCS;
- shaping and indication of the ground speed and drift angle;
- shaping and indication of the desired track and track angle error (for the purpose of automatic control) and entering these data into the AFCS to enable automatic flight along a pre-programmed route;
- non-stop automatic indication of the aircraft's current position on a moving-map display (MMD).

The NK-144 suite was developed by the Tupolev OKB under the supervision of Leonid L. Kerber; later he left the OKB and was succeeded by V. P. Sakharov as NK-144 project chief. Early-production Tu-144s, including CCCP-77102 which was transferred to LII for test and research work, served as avionics testbeds for the ABSU-144 AFCS, IS-1-72 inertial navigation system, AIS astro-inertial navigation system, RTO data link system and a speed/altitude data system.

In designing the Tu-144 the Tupolev OKB was confronted for the first time with the need to tackle ecological problems and with the world community's growing environmental awareness. This concerned first and foremost the sonic boom – sudden loud noises reminiscent of thunderclaps or explosions caused by the shock waves generated by a jet travelling at supersonic speed; depending on the aircraft's configuration, speed and other factors, occasionally it may create a double or even triple 'boom'. These dreadful sounds heard in the areas where test flights (and later practice flights of combat aircraft) were taking place not only frightened people and animals, they could also shatter windows and cause other minor damage.

LII undertook theoretical research and flight experiments to study this phenomenon, using Mikoyan/Gurevich MiG-19 and Sukhoi Su-9 fighters and Tu-22 bombers. The experiments showed that the severity of the sonic boom depended on the atmospheric conditions, the flight mode and the aircraft's size and layout. When environmental protection movements became increasingly vocal, lobbying against SSTs, this served as an incentive for more detailed research into the problem; Su-15, MiG-21 and MiG-25 interceptors, and later the MiG-21I proof-of-concept vehicle, were used at this stage. The Tu-144's flight test programme included special acoustic measurements along the flight track. These allowed the most 'offensive' flight modes to be defined, namely acceleration and the early phase of cruise flight; the pressure increase at the forefront of the shock wave in these modes was 11-13 kg/m^2 (2.25-2.66 lb/sq ft) at Mach 1.3 and 10-11 kg/m^2 (2.05-2.25 lb/sq ft) respectively.

Similar research was done in the USA, France and Sweden; opinion polls were held in areas regularly 'boomed' by supersonic jets. After much discussion at the international level the International Civil Aviation Organisation (ICAO) officially acknowledged that sonic boom was permissible but only on overwater flights. It was recommended that each member nation should decide for itself whether sonic boom was permissible on overland flights. Most of the ICAO member nations imposed bans on SST operations over land, but the Soviet Union and India refused to toe the line.

Knowledge of the problem accumulated by then suggested that the sonic boom could not be eliminated completely, as an aerial vehicle travelling at speeds above the speed of sound inevitably generated shock waves and areas of vacuum. The correct way to go was 'if you can't beat 'em, cheat 'em': the flight routes of SSTs had to be plotted over water or sparsely populated areas, circumventing built-up areas, and a composite subsonic/supersonic flight profile was to be used. Furthermore, the force of the sonic boom could be reduced somewhat by optimising the aircraft's shape (a 'low-boom aircraft').

Still, the ambient noise issue (the first ICAO noise regulations were introduced concurrently with the development of the first-generation SSTs) could not become the decisive factor affecting the choice of the aircraft's layout. The cost factors associated with the engines powering a supersonic airliner require the engines to have the lowest possible bypass ratio; this, in turn, results in a higher exhaust jet velocity and hence higher noise. Now since an SST's field performance is inevitably worse than that of a similarly sized subsonic airliner (because of the SST's low aspect ratio delta wings), their noise levels cannot be equivalent; an SST needs more thrust and is thus noisier. This is especially true for the noise levels alongside the runway, which are almost entirely determined by the engines' efflux. Taking all of this into consideration, after a number of work sessions the ICAO's Noise Committee deemed it possible to permit operation of the first-generation SSTs (the Tu-144 and the Concorde) with the noise levels which their designers had managed to obtain ('they did the best they could'). In the case of the Soviet SST the noise level on take-off could be safely reduced by throttling back the engines immediately after becoming airborne; this was possible thanks to the greater thrust/weight ratio and the better aerodynamics afforded by the canard foreplanes. The noise level during final approach was again reduced by throttling back the engines and by reducing the approach speed (once again thanks to the canards). Furthermore, the Tu-144D was quieter than the Tu-144 *sans suffixe* thanks to the higher mass flow of the RD36-51A engines. All things considered, the Tu-144 had a lower noise signature than the Concorde.

Since the SSTs were to cruise at 16,000-18,000 m (52,490-59,050 ft) instead of the 10,000-11,000 m (32,810-36,090 ft) typical of subsonic airliners, the possible effect of solar and space radiation on the aircraft and its occupants needed to be explored. At the initial stage of the SST programme this issue was quite acute and was studied both at the national level and by international organisations – ICAO and the International Radiation Protection Agency. The Tu-144's development and test programme included a special

effort to develop an on-board radiation metering kit and ground-based systems for predicting dangerous solar radiation levels. Subsequent events, however, showed that the fears were exaggerated; on the routes chosen for the SSTs the radiation levels were not so high as to damage the health of the crew and passengers. Any real danger could only arise in the event of a sudden burst of solar activity, especially during operations in high latitudes. In that case the only chance to get out of harm's way was to execute an emergency descent, and the procedure was duly developed and verified by the Tupolev OKB.

Apart from the design problems described above, the production of such a radically new aircraft as the Tu-144 created a spate of technological problems that had to be tackled by all branches of industry having to do (in whatever degree) with aviation. This especially concerned the new structural materials, instruments and equipment used and the manufacturing technologies involved; the technological leap for the Soviet aircraft industry brought about by the Tu-144 was comparable to the one when the Tupolev OKB reverse-engineered the Boeing B-29 Superfortress in the late 1940s as the Tu-4. The D16 series duralumin alloys widely used by the Soviet aircraft industry in the early 1960s were no good for an aircraft with a long service life designed for operation at skin temperatures of 100-130°C (212-266°F). New aluminium alloys, such as the AK4-1, had to be developed and the technologies of processing them devised; among other things, a two-stage sheet metal rolling process was invented. The chemical composition of the alloy had to be altered by sharply reducing the silicone content to improve fatigue resistance. To enable the manufacture of wings with a high load ratio the Soviet metallurgical industry had to master production of AK4-1 alloy parts up to 9 m (29 ft 6$^{11}/_{32}$ in) long, up to 2 m (6 ft 6¾ in) wide and up to 65 mm (2$^{9}/_{16}$ in) thick. Such items were rolled from slabs weighing up to 3 tons (6,610 lb) and manufactured using a new uniform alloying technology to alleviate linear stresses.

To prevent machined skin panels from warping a new technology of stretching the half-finished articles after the rolling process was introduced. In accordance with a Tupolev OKB request a stretching machine delivering a force of more than 6,000 tons (13,227,500 lbf) was created and installed at the Verkhnyaya Salda Metal Foundry.

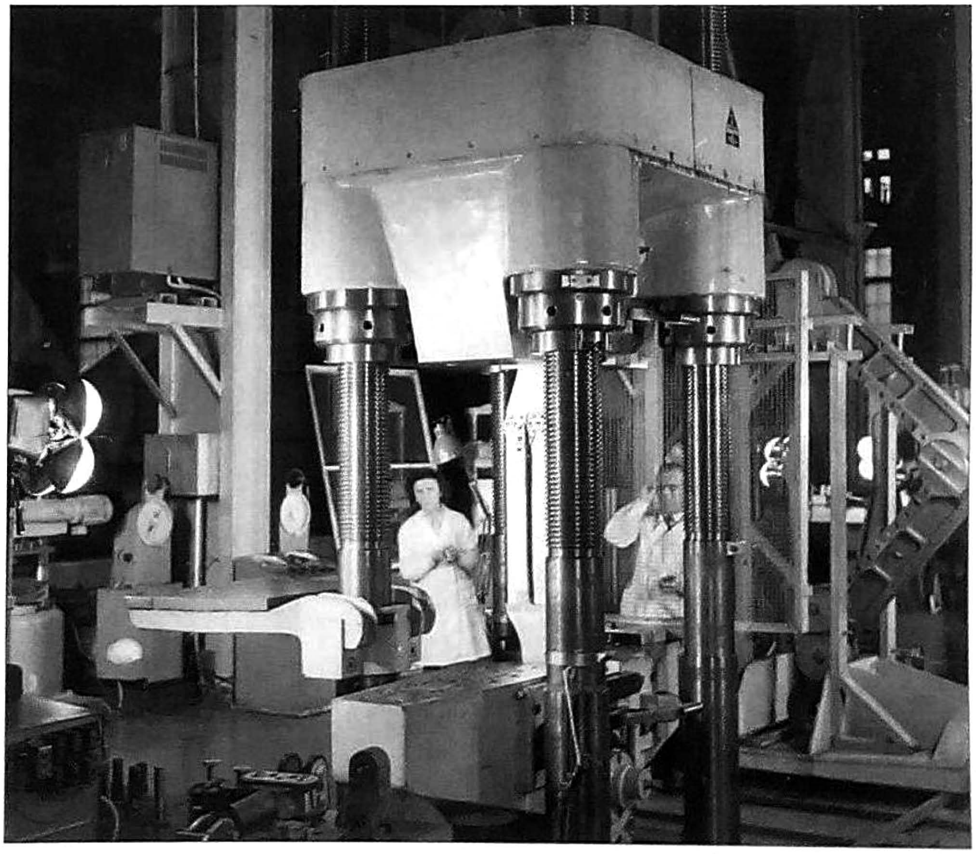
Considerable success was achieved with introducing titanium alloys which were used on an unusually wide scale in the Tu-144's design. As late as 1958 the share of titanium in a typical Soviet aircraft's airframe was less than 0.5%; on the Tu-144 it rose to an unprecedented 15% of the airframe weight. The Tupolev OKB's experimental shop in Moscow (MMZ No.156 'Opyt'; MMZ = *Moskovskiy mashinostroitel'nyy zavod* – Moscow Machinery Plant; the name translates as either 'experiment' or 'experience') set up a specialised titanium processing section; even angle pieces and other small items of sheet titanium for the prototype's airframe were manufactured there, as the Soviet aircraft industry could not supply such items ready-made. Most of the large titanium components for the prototype and several production machines were welded and annealed at the *Severnyy Zavod* (Northern Plant) in Leningrad, the only plant in the Soviet Union which had the requisite equipment. A technology for welding titanium honeycomb structures was developed jointly with the Aviation Technology Research Institute (NIAT) and the Metallurgical Institute (IMET).

The temperatures at which the Tu-144 would operate necessitated a large amount of research on a new generation of dielectric materials, such as sealants working in hot air and hot fuel or fuel vapour mediums, glass-fibre reinforced plastic for the radome, heat insulating materials, foam plastics, Perspex for the flightdeck and cabin windows, heat-resistant bonding agents, cabin wall liners and so on. Heat-resistant wires, previously imported, were mastered by Soviet industry; these included wires designed for strong currents, which allowed the cross-section (and hence the weight of the wiring) to be reduced.

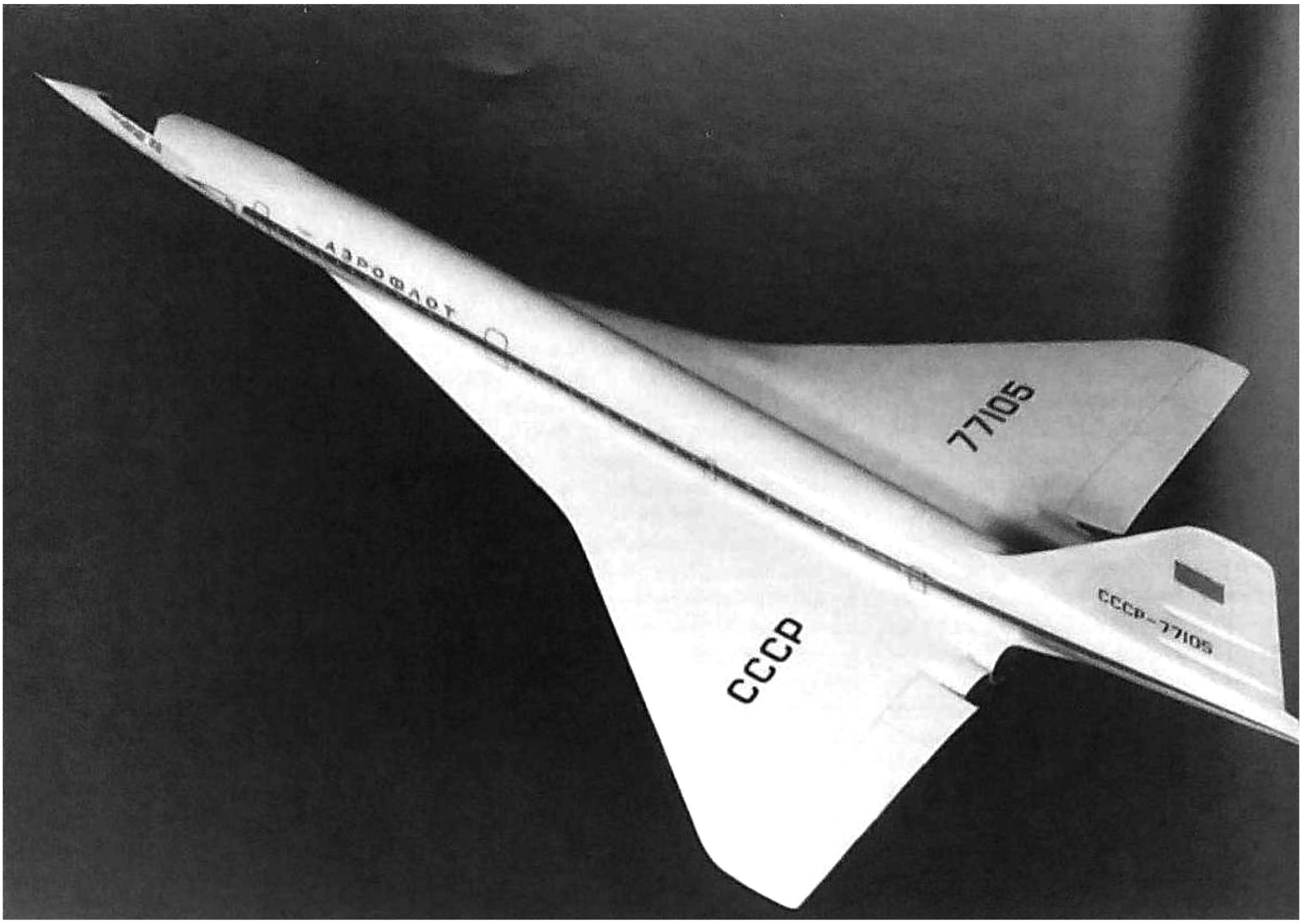
The Tupolev OKB built more than 80 test rigs in the course of the programme. These included propulsion system rigs, a fuel system rig allowing hot and cold fuel conditions to be explored, an experimental fuel nitrogenation unit, static electricity and lightning protection rigs, an 'iron bird'/flight simulator for the control system, test rigs for the fire suppression system, landing gear, ACS/dynamic heat insulation and so on, plus static test facilities for the complete airframe and separate subassemblies. All of this made it possible to evolve a system of hardware failure assessment, reducing the number of simulated failures to be tested in actual flight conditions.

The Tu-144 programme required a complete shake-up of the Soviet aircraft industry's metallurgical, structural material and machine tool branches. For instance, the use of milled panels required the development and introduction of computer-controlled milling machines, which were created by the Savyolovo Machinery Plant. Shot-blasting technologies were introduced as a means of shaping and reinforcing the surface of skin panels.

Andrey N. Tupolev, who always cared a lot about aviation technologies, personally co-ordinated the efforts to introduce new materials and production methods as part of the Tu-144 programme. This was a monstrous effort, and much of this burden was shouldered by the brilliant technologist I. B. Iosipovich (during the Great Patriotic War



One of the test rigs used during the Tu-144's development.



A desktop model of CCCP-77105, the Tu-144D prototype. The wing shape of the production model is shown to advantage.

he had organised production of the Tu-2S bomber at Moscow-Fili in his capacity as Director of plant No.23), MMZ No.156 chief engineer A. V. Meshcheryakov, chief technologist S. A. Vigdorchik, chief metallurgist I. L. Golovin and deputy chief engineer V. P. Nikolayev. Mention should be made of M. A. Bormashenko, who often worked wonders in procuring hard-to-obtain structural materials for MMZ No.156, the dielectric materials section chief B. A. Peshekhonov, the plant's Director V. I. Borod'ko and others working as a close-knit and dedicated team.

The new alloys' properties, which were not stated in the available literature, had to be studied. Hence the OKB set up a new division called Technological Laboratories Section (OTL – *Otdel tekhnologicheskikh laboratoriy*). This section worked in close contact with such notable research establishments as the All-Union Institute of Aviation Materials (VIAM – *Vsesoyooznyy institoot aviatsionnykh materiahlov*), the All-Union Institute of Light Alloys (VILS – *Vsesoyooznyy institoot lyohkikh splahvov*), the Central Research Institute of Ferrous Metals (TsNIICherMet), NIAT and so on. This co-operation helped a lot to introduce the titanium alloys that are indispensable for a supersonic aircraft. Titanium alloys are stronger and stiffer than aluminium (and even steel, in some circumstances) and can withstand temperatures up to 400°C (752°F); they also have high corrosion and fatigue resistance. Also, titanium lends itself well to welding, allowing rivet or bolted joints to be eliminated and a weight saving achieved. The VT-6, VT-20, OT-4 and OT-4-1 alloys were best suited for constructing the airframes of supersonic jets.

The OKB explored the influence of atmospheric gases (oxygen, hydrogen and nitrogen) on the properties of titanium alloys. MMZ No.156 had to manufacture its own argon welding chamber for working with titanium parts; it was not until 1968 that NIAT developed a full-size argon-arc welding/annealing chamber and had it manufactured for the Tupolev OKB. The OKB also developed a whole set of technological guidelines for working with titanium that were later adopted by the Soviet aircraft industry. Among other things, MMZ No.156 developed a method of manufacturing titanium honeycomb-core panels with a filler of 0.08-mm VT-15 titanium foil (supplied by the Verkhnyaya Salda Metal Foundry). Panels measuring up to 500 x 1,000 x 80 mm (1 ft 7 11/16 in x 3 ft 3 3/8 in x 5 15/32 in) were manufactured by diffusion welding in a vacuum furnace at 950-1,050°C (1,724-1,922°F).

The Tu-144 also triggered the wide use of the following alloys:

• AK4-1 aluminium alloy (sheets 0.5-1.0 mm thick, up to 1.5 m (4 ft 11 in) wide and up to 7 m (22 ft 11 19/32 in) long, extruded profiles up to 150 mm (5 29/32 in) deep and up to 10 m (32 ft 9 45/64 in) long, forged and rolled slabs up to 63 mm (2 31/64 in) thick and measuring up to 9 x 1.6 m (29 ft 6 21/64 in x 5 ft 3 in);

• V93 aluminium alloy stampings;

• AL-10 high-strength aluminium alloy and ML-10T6 magnesium alloy castings;

• OT-4 and OT-4-1 titanium alloy (sheets 0.3-12.0 mm (0.01-0.47 in) thick, up to 1.2 m (3 ft 11 1/4 in) wide and up to 4 m (13 ft 1 31/64 in) long, extruded profiles up to 3.5 m (11 ft 5 51/64 in) long, slabs 35-60 mm (1 3/8-2 23/64 in) thick and stamped parts);

• VT-22 high-strength titanium alloy (precision stamped parts);

• VT-16 high-strength titanium alloy (cold- and hot-rolled rods for making fasteners);

• VT-5L high-strength titanium alloy (castings measuring up to 0.8 x 1.2 m / 2 ft 7 1/2 in x 3 ft 11 1/4 in).

Take One... Take Two

Tu-144 Versions

Tu-144 First Prototype/Demonstrator (*Izdeliye* 044)

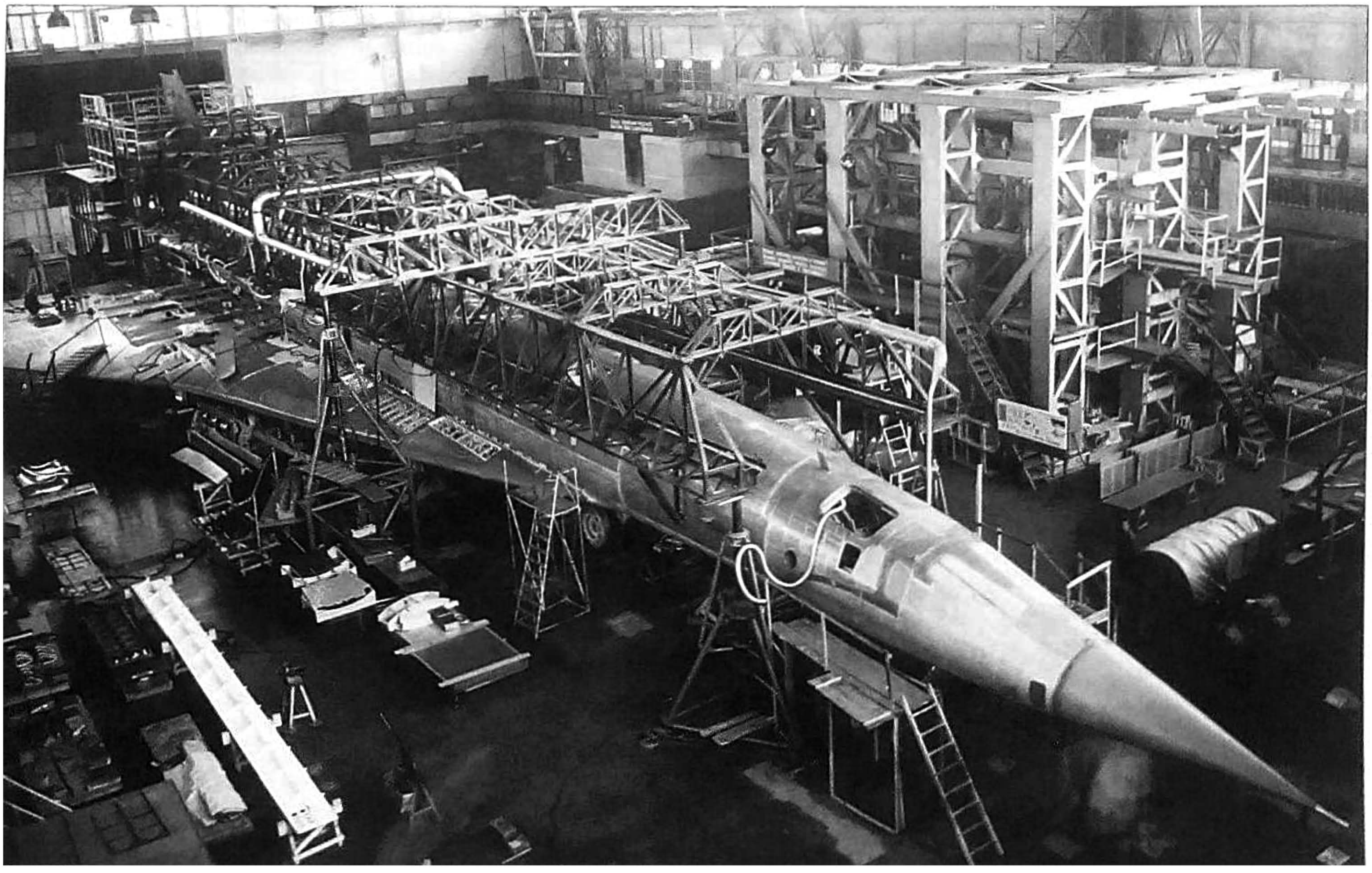
Because of the many problems arising in the course of the Tu-144's development the Tupolev OKB decided to begin the hardware stage of the programme with what, in today's terminology, could be described as a demonstrator aircraft. This aircraft would verify the fundamental aerodynamic features, structural strength solutions, systems and equipment devised for the Tu-144 and help to create a viable supersonic airliner. Importantly, in the course of its flight tests the demonstrator would provide the answers that would require more time and greater expenditures to obtain, using ground test rigs – notably, it would prove the validity of the calculation methods used.

Airliner and transport aircraft prototypes are always provided with devices allowing the crew to parachute to safety if things go terribly wrong. However, since bailing out was unthinkable at supersonic speeds, the unprecedented decision was taken to equip the Tu-144 demonstrator with ejection seats.

Known at the OKB as *izdeliye* 044, the Tu-144 prototype was a qualitatively new kind of aircraft requiring an altogether different approach to aircraft design, manufacturing and operation. Even at the preliminary design (PD) stage it became clear that the basic performance targets could only be met if the aircraft possessed the maximum possible lift/drag and payload/weight ratios. This dictated the choice of the tailless-delta layout, the closest you can get to the 'flying wing' layout having the minimum number of supporting surfaces. This layout allowed the conflicting requirements to be reconciled, providing a high lift/drag ratio in supersonic cruise, a high payload/weight ratio and good low-speed handling.

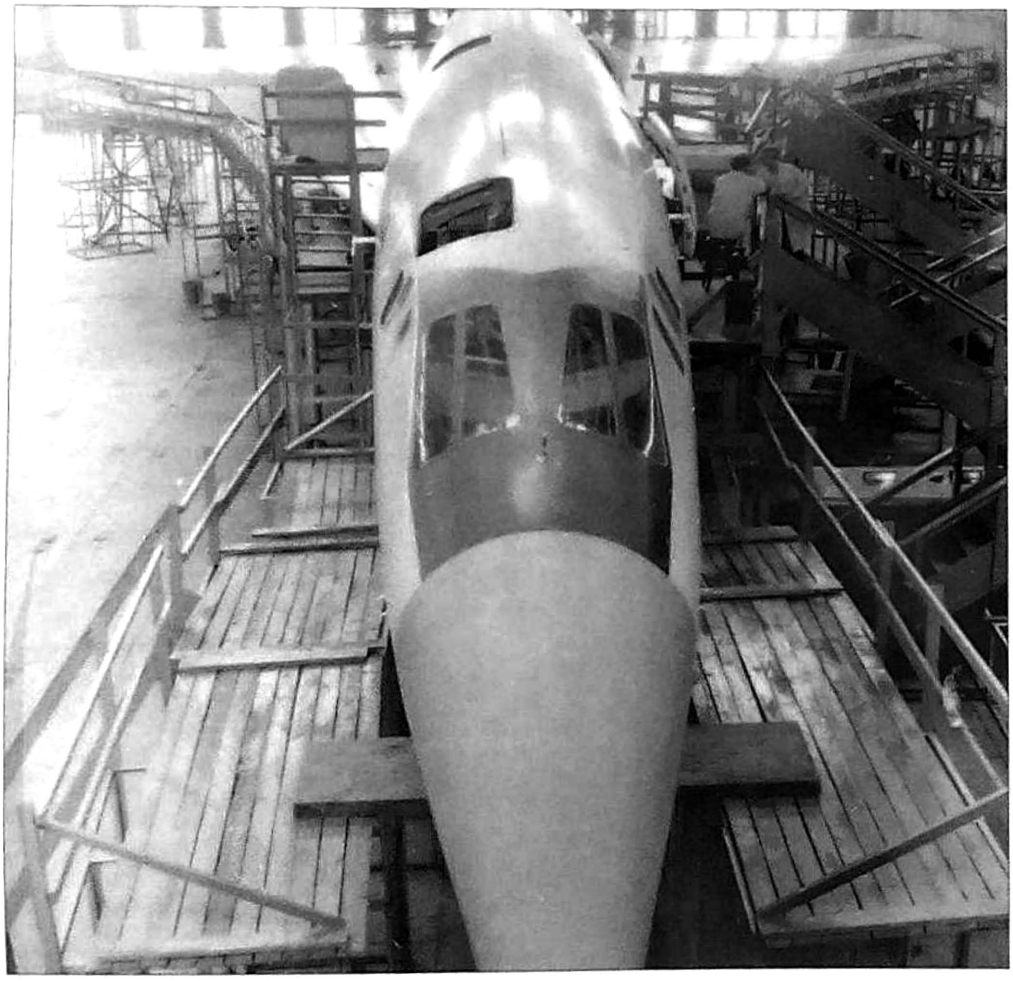
The Tu-144's flight envelope was determined not only by the speed and altitude parameters but also by the airframe temperature and centre of gravity position, both of which are affected heavily by the current Mach number. The significant shift of the wing focus when the aircraft goes supersonic means that the CG position has to be altered before cracking Mach 1. The thrust required for passing the transonic speed range (Mach 0.95-1.2) determines the engines' thrust class. Thus, the Tu-144 is a multi-mode aircraft as regards speed, temperature and CG position.

Because of the chosen general arrangement the airframe's aeroelasticity has a considerable influence on the aircraft's aerodynamics, stability and handling. The peculiarities of the aircraft's aerodynamics at supersonic speeds (boundary layer pulsation



The first prototype Tu-144 (*izdeliye* 044) nearing completion at MMZ No.156. Note the ejection hatches.

Above: The forward fuselage build-up area, with the rear fuselage (already out of the assembly jig) and the rear pressure dome lying alongside.

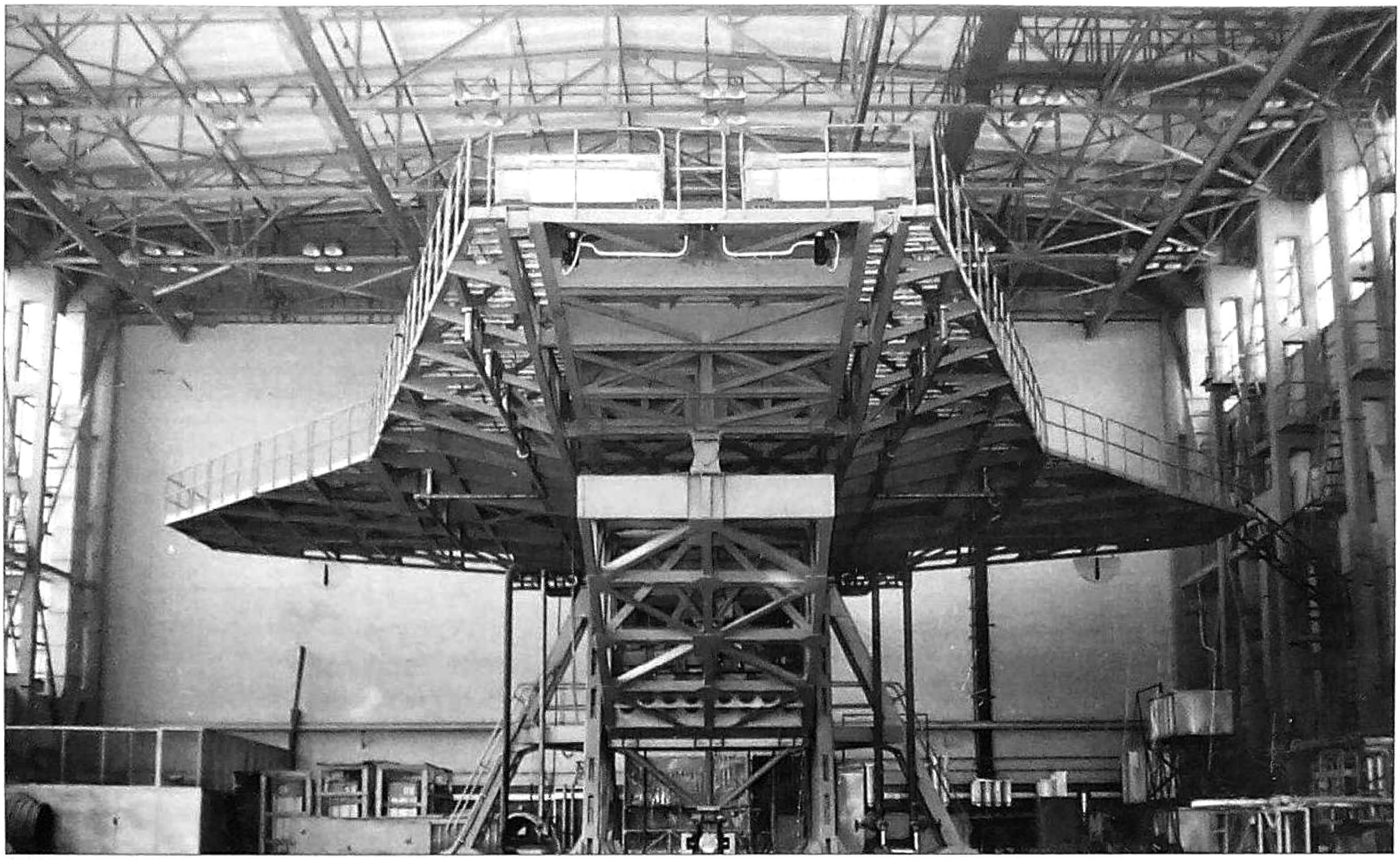


The almost completed prototype shows the location of the ejection hatches and hence the crew stations.

and vortex generation) determined the stiffness requirements applying to the skin panels; these became the primary criterion when it came to the choice of structural materials and detail design. The designers selected an ogival planform for the wings, with leading-edge root extensions (LERXes) and an S-shaped leading edge; this led to most of the weight being housed in the fuselage, which had a noticeable effect on the wing loading.

The Tu-144's designers strove to achieve high aerodynamic efficiency by utilising a fuselage with a high fineness ratio and thin wings. This, however, led to significant flexing of the airframe in flight, and the Tu-144 was shaped with due regard to these elastic deformations. All elements of the airframe were optimised to minimise the aerodynamic losses caused by longitudinal trim, including the shape of the wing centre section surface and even the angle at which the engine nozzles were set relative to the fuselage axis, and a trim tank was incorporated into the fin to which part of the fuel was transferred to shift the CG aft in supersonic cruise.

Numerous models were tested in TsAGI's subsonic and supersonic wind tunnels to check the efficacy of the newly devised features. At the same time, at Andrey N. Tupolev's initiative the OKB-155 'fighter maker' design bureau led by Artyom



Above: One of the many test rigs constructed as part of the Tu-144's development programme. This one served for testing the fuel system.

I. Mikoyan was tasked with developing a sub-scale proof-of-concept vehicle that would verify the airliner's tailless-delta layout in actual flight. The Mikoyan OKB took the fuselage, engine and landing gear of the MiG-21S fighter, mating them with new ogival wings which were a scaled-down copy of the Tu-144's, featuring 78° leading-edge sweep on the inboard one-third of the span and 55° outboard. Two examples of this hybrid designated MiG-21I were built; the aircraft was also known as the A-144, *izdeliye* 21-11 or simply as the Analogue, the latter name meaning that it was analogous to the Tu-144. Even with all necessary information provided by the Tupolev OKB, the design work on the MiG-21I was making slow progress and was holding up the Tu-144 programme as a result. Legend has it that Andrey N. Tupolev became the bane of Mikoyan's existence for a while, urging him to complete the aircraft as soon as possible. Each morning he would position himself under the window of Mikoyan's apartment and call out loudly in an exceptionally plaintive voice: *'Artyom Ivanovich, when are you going to give me my Analogue?'*, much to the amusement of everyone who happened to be within earshot – except Mikoyan himself.

The Tu-144's multi-mode ideology was reflected in all of its systems and components. Virtually all of them featured either variable geometry (such as the air intakes) or a

The prototype's port outer wing is moved into position prior to mating with the wing centre section.

Above: An interesting shot of two very different Tu-144s together in a hangar at MMZ No.156. The original prototype (*izdeliye* 044, CCCP-68001) is in the foreground, with the first production-standard *izdeliye* 004 (CCCP-77101) in the background.

A three-quarters rear view of the prototype amidst a mesh of work platforms in the hangar.

Marshal Dmitriy F. Ustinov, the Soviet Minister of Defence (second from right) inspects the first-class cabin of the Tu-144. Note the enclosed overhead baggage bins which appear to be of rather limited capacity.

variable operating cycle (such as the air conditioning system).

After analysing the powerplant arrangements of the heavy supersonic jets developed by the Tupolev OKB over the years, the designers chose to place all four engines side by side in a common housing adhering to the wing centre section undersurface so that the nozzles were in line with the wing trailing edge. The front end of the engine housing was split into two pairs of two-dimensional air intakes with sharply raked leading edges, each pair being divided by a vertical splitter. This underwing placement of the air intakes made for high efficiency in supersonic cruise and relatively low drag, justifying the weight penalty imposed by the long inlet ducts. The narrow space between the port and starboard pairs of intakes accommodated a fairing of triangular cross-section housing the tall aft-retracting nose landing gear unit, the cleft gradually vanishing aft of this fairing; the original project configuration featuring four intakes in a row with three splitters in between was rejected due to intake/nose gear integration problems and the risk of foreign object ingestion. The air intakes had horizontal airflow control ramps.

The common engine package offered several advantages over the widely spaced twin-engine nacelles used on the Concorde. The long inlet ducts required to ensure adequate surge resistance could be incorporated quite easily, the location of the engines close to the centreline reduced the yaw caused by thrust asymmetry in the event of an engine failure, and the wing downwash in the area of the intakes was reduced. Placing the intakes well forward made it easier to protect them and the engines against foreign-object damage (FOD). Flutter resistance was improved, the control runs and piping for the engines could be made shorter, and a greater proportion of the wing trailing edge was available for the control surfaces. On the minus side, in addition to the abovementioned weight penalty, the considerable thickness of the turbulent boundary layer required the air intake lips to be set far apart from the wing undersurface. Also, as already mentioned in the previous chapter, flight tests revealed subsequently that the rear fuselage tended to get excessively hot because of the engines being located so close to it.

Another side effect of the common engine package was that the main gear units could only be stowed in the wings outboard of the engine housing; considering the low thickness/chord ratio and the limited space within the wings, this turned into a real problem. Yet, the designers came up with an ingenious solution. In order to fit inside the wing airfoil each main gear bogie had no fewer than 12 small wheels in three rows of four, with a wide track; this gave the additional benefit of increasing the landing gear footprint and reducing the runway loading. During retraction the main gear bogies somersaulted forward to lie inverted in the wheel wells. This did the trick, albeit the wheel well doors still had to be suitably bulged. Additionally, to minimise the space required the main gear struts had a cunning 'knee-action' design, the small upper segment swinging aft and the rest of the oleo forward (a similar solution had been used by Grumman on the F8F Bearcat) and the bogies were hinged close to the rear axle so that most of the bogie lay against the oleo, reducing the overall length when stowed.

Assembly of the *izdeliye* 044 prototype (c/n 00-00 – that is, batch zero, aircraft zero) began in 1965 together with a static test airframe; both were built by the OKB's experimental plant, MMZ No.156 'Opyt', with some of the subassemblies being supplied by the OKB's other branches. Bearing the custom registration CCCP-68001 (that is, 1968, Tu-144 No.001), the aircraft was largely completed in October 1968 and transported to the LII airfield in the town of Zhukovskiy south of Moscow where OKB-156 had its flight test facility. There the remaining systems components were installed and the finishing touches

Left: Marshal Dmitriy F. Ustinov and other Soviet government officials descend the gangway after examining the interior of a production Tu-144.

Below left: Ustinov and other high-ranking Ministry of Defence and MAP executives inspect the Tu-144 production line at the Voronezh aircraft factory. Ustinov appears to be impressed.

applied. Meanwhile, LII began tests with the MiG-21I proof-of-concept vehicles, the first of which (even more eloquently registered CCCP-144) first flew on 18th April 1968; they were flown by a number of test pilots, including Oleg V. Goodkov, Eduard V. Yelian and Mikhail V. Kozlov. The MiG-21I flew successfully at speeds up to 2,500 km/h (1,552 mph), providing data used for final design adjustments to the Tu-144's wings, as well as giving test pilots experience in flying an aircraft with ogival wings. Unfortunately, CCCP-144 eventually crashed fatally right in the middle of the runway at Zhukovskiy when the pilot decided to show off, performing a barrel roll at low altitude and losing control.

Engine runs, taxying tests and final ground checks went on for a month. By 20th December 1968 CCCP-68001 was finally ready to fly but the weather was inclement, with fog and low cloud, leaving no chance for the flight. Being anxious about the flight test schedule (the Soviet SST had to make its maiden flight ahead of its Anglo-French counterpart by all means, as a matter of national prestige), the Ministry of Aircraft Industry went so far as to enlist the services of a special Aeroflot detachment operating 'sky cleaner' aircraft to improve the weather over Zhukovskiy. Still, Mother Nature refused to play ball. When the 'sky cleaners' had done their job and the weather was acceptable, the go-ahead was given to tow the Tu-144 to the runway holding point. However, even as the aircraft moved, so thick a fog descended all of a sudden that the visibility dropped to 15-20 m (50-65 ft). Of course, the first flight had to be called off; gingerly and with great difficulty the Tu-144 was towed back to the hardstand.

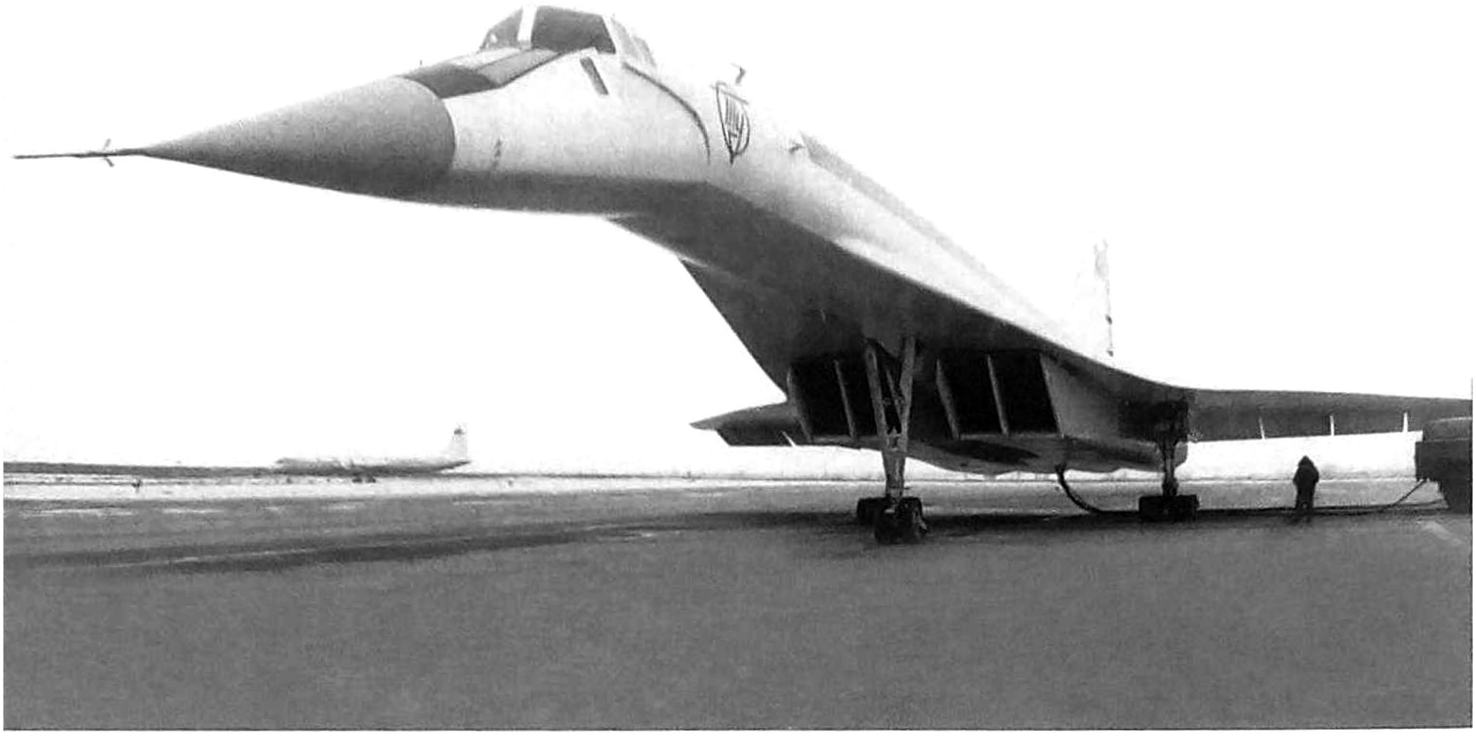
A harrowing week or so followed; the flight and ground crews involved in the Tu-144 programme were on tenterhooks, coming to the flight test facility in the early morning hours day after day in the hope of a change in the weather. The bad weather persisted until New Year's Day; 31st December 1968 dawned with brilliant sunshine at last, but soon afterwards the weather began deteriorating again. Minister of Aircraft Industry Pyotr V. Dement'yev declined to make a decision, saying 'It's up to you to decide [whether to fly or not]', and left the airfield, going back to Moscow. As soon as the sun broke through the clouds again, Andrey N. Tupolev gave the order to proceed. The engines were promptly started and, 25 seconds after beginning its take-off

Above: Tupolev OKB design staff assemble beside the Tu-144 prototype during a ceremony dedicated to the aircraft's completion. Note the unusually large Tupolev OKB logo on the nose

run, the Tu-144 left the ground for the first time, with MiG-21I CCCP-144 and a Tu-124 airliner flying chase. The SST was flown by a crew comprising captain Eduard V. Yelian (holder of the Hero of the Soviet Union and Merited Test Pilot titles), co-pilot Mikhail V. Kozlov (Merited Test Pilot), flight engineer Yuriy T. Selivyorstov and project engineer V. N. Benderov who held overall responsibility for the test programme.

The 37-minute flight went without a hitch, except that the weather deteriorated again and the first landing of the world's first SST had to take place in conditions in which many production airliners of the day were obliged to stay on the ground. The pilots reported that the machine flew well and responded well to the controls.

A YaAZ-210D 6x4 tractor unit modified as an airfield tug (Moscow Region number plates 21-73 YuAU) pushes Tu-144 CCCP-68001 back into a hangar at the Tupolev OKB's flight test facility in Zhukovskiy.



Above: The Tu-144 prototype, CCCP-68001, on the apron at Moscow/Vnukovo-1. In the background an Aeroflot IL-18 taxies out for take-off from runway 24.

This first flight of the Tu-144 was not just a great New Year present for everyone concerned but an event of world significance and a milestone in the history of Soviet aviation. The objective of being the first past the post had been attained; the Concorde 001 prototype (F-WTSS) flew only on 2nd March 1969.

On the 20th and 21st May 1969 Tu-144 CCCP-68001 made its public debut at Moscow-Sheremet'yevo airport where it was demonstrated statically to Soviet and foreign media representatives and civil aviation specialists. It was then that the NATO's Air Standards Co-ordinating Committee (ASCC) assigned the reporting name *Charger* to the Tu-144; at the same time, however, a more popular nickname was born, 'Concordski'. This sobriquet stuck to the Tu-144 for the rest of its life, hinting at the alleged Soviet custom of copying Western designs.

On 1st June 1970 the aircraft went supersonic for the first time. A month and a half later, on 15th July, CCCP-68001 attained its maximum speed of 2,443 km/h (1,517 mph) or Mach 2.35. From 25th May to 8th June 1971 the Tu-144 was presented to the Western world 'live' at the 29th Paris Air Show, rubbing noses with its Western counterpart, the Concorde, for the first time.

Subsequently the Tu-144 demonstrator made a series of publicity flights to Prague-Ruzyne, Berlin-Schönefeld, Warsaw-Okęcie, Budapest-Ferihegy, Hannover and Sofia-Vrazhdebna; the flights from Moscow to Sofia and back were made in supersonic cruise mode. The results obtained in the course of the tests confirmed the validity of the design principles and the efficacy of the design features incorporated into the aircraft and were later used in the development of the production version described below.

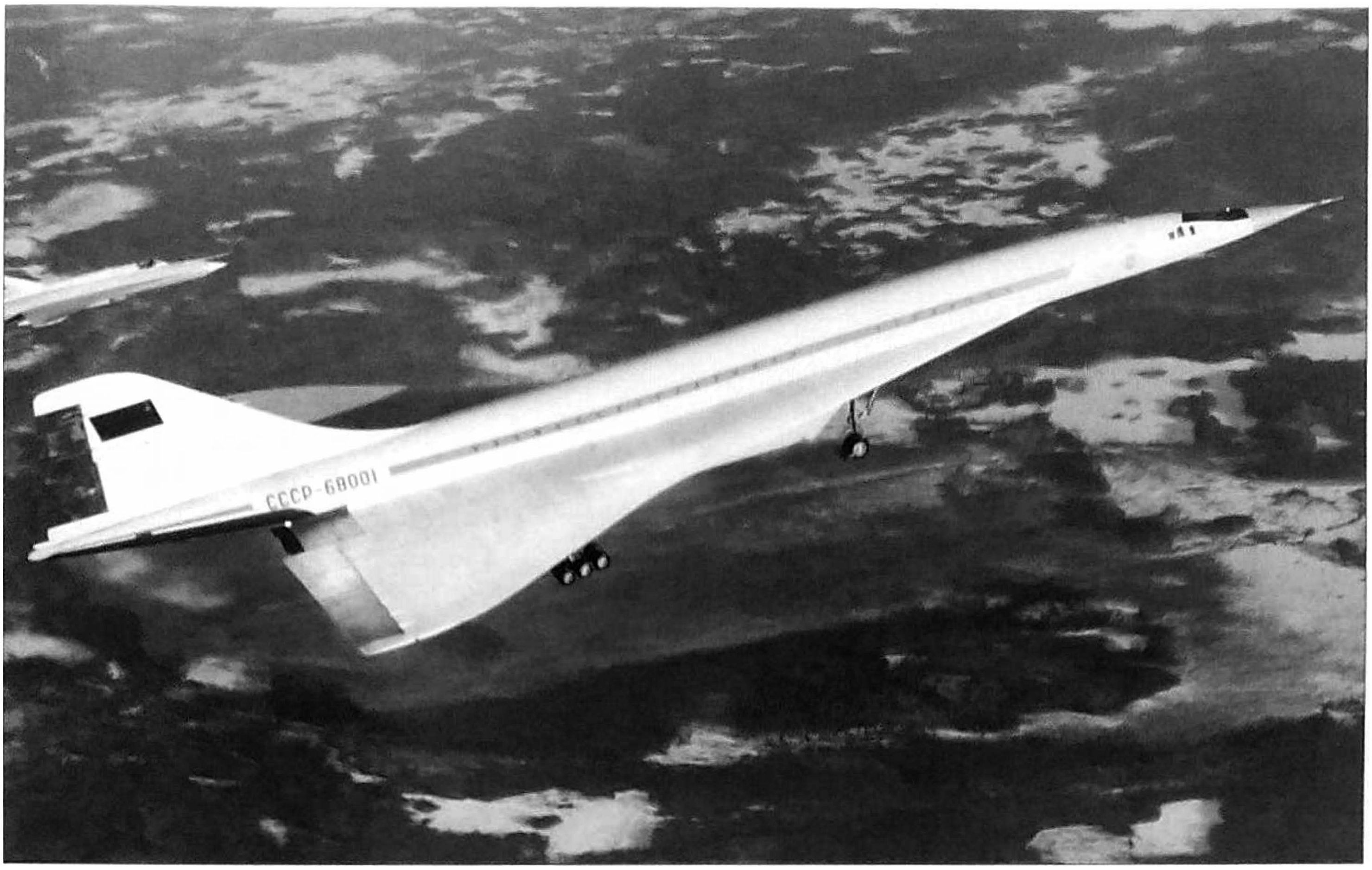
CCCP-68001 continued flying test missions alongside its radically different production namesakes until 27th April 1973 when it was struck off charge; at that point it had made more than 120 flights, with a total time since new of 180 hours (including about 50 hours at supersonic speeds). On the whole the demonstrator had served its intended purpose well. Sadly, this aircraft was ultimately broken up, though it really should have been preserved for posterity.

The development, construction and testing of the Tu-144 demonstrator (*izdeliye* 044), and the additional research at TsAGI and the Tupolev OKB that followed, furnished invaluable data and experience. This was taken into account when creating the production version – a very different aircraft in which many of the deficiencies discovered on the demonstrator had been designed out. The production Tu-144 differed markedly from the *izdeliye* 044 as regards aerodynamics, structural design and performance.

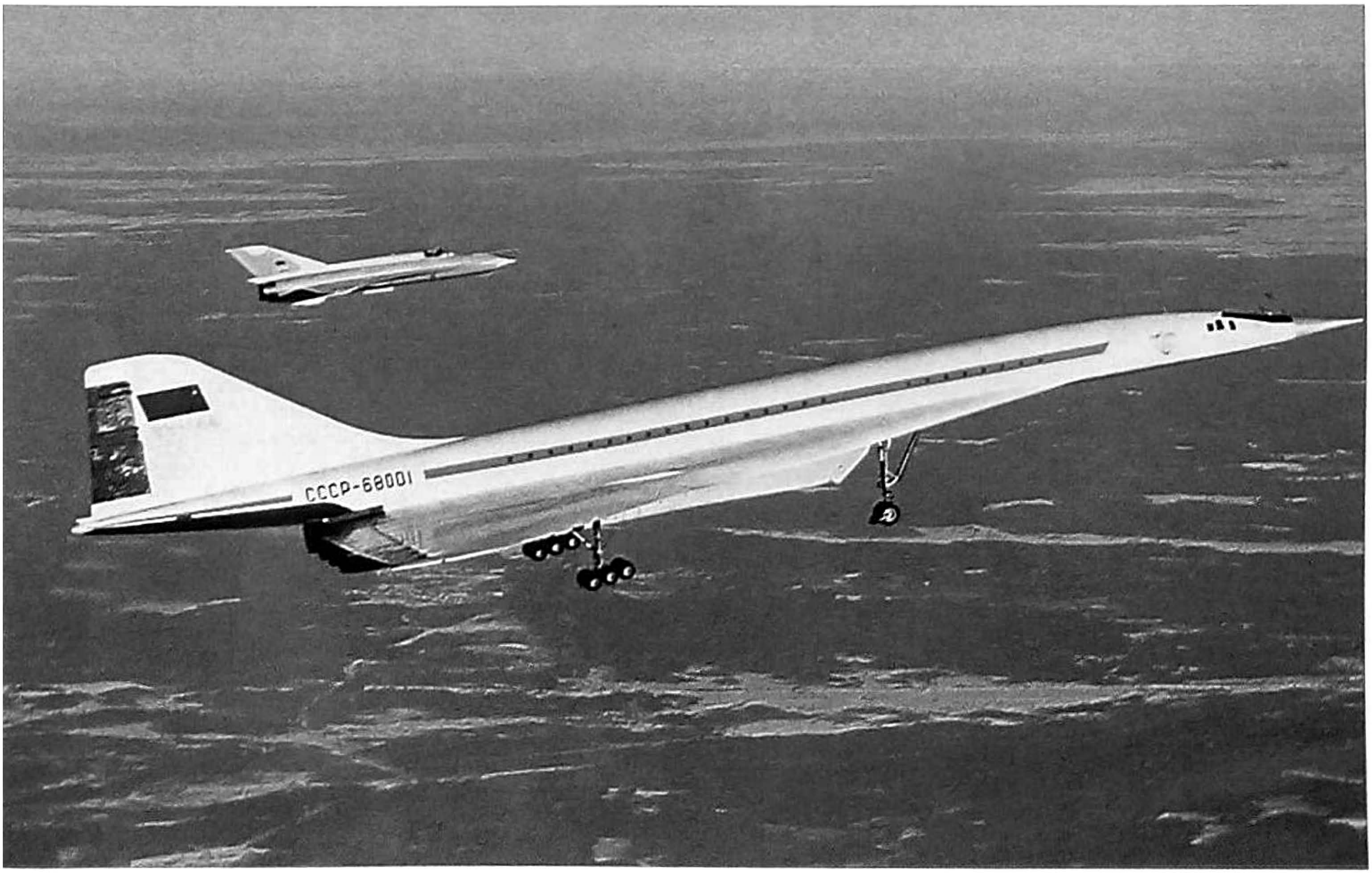
Tu-144 Supersonic Airliner (Production Version, *Izdeliye* 004)

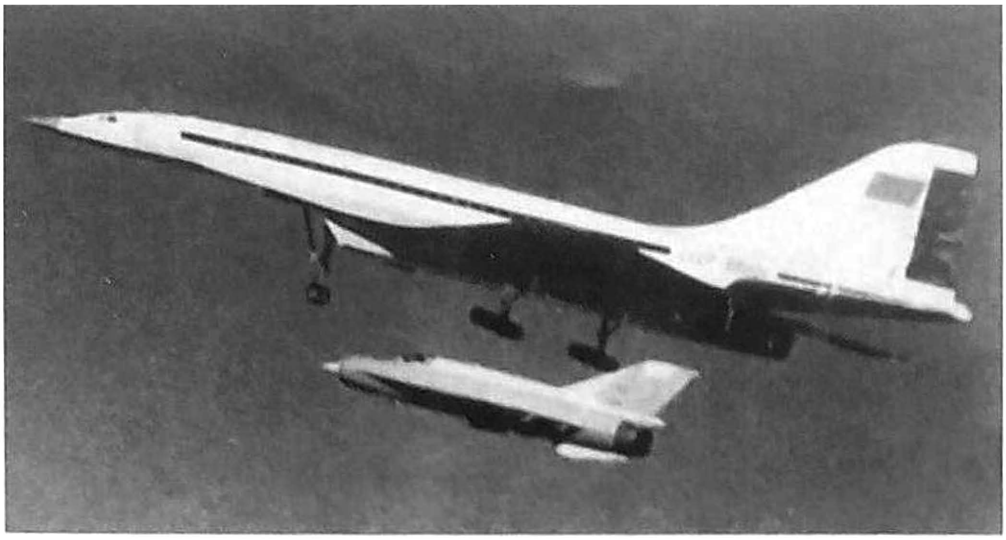
The tests of the first Tu-144 revealed a number of design shortcomings. In particular, the close proximity of the engine exhausts to the rear fuselage caused strong vibration and heating which not even the titanium elements in the airframe could withstand. The flight performance, too (especially range), left something to be desired. Thus, when the testing of the *izdeliye* 044 was over, it was decided to build no more and begin a major redesign.

Development work took two directions: the installation of the new, more fuel-efficient Kolesov RD36-51 non-afterburning turbojets (then under development at the OKB-36 aero engine design bureau in Rybinsk) and substantial improvements to the structure and aerodynamics of the airframe. These were to produce a SST with the necessary range. As early as 1969 the CofM Presidium's Commission on Defence Industry Matters (VPK – *Voyenno-promyshlennaya komissiya*) passed a ruling requiring the Tu-144 to be powered by RD36-51 engines. At the same time it was decided that a joint MAP/MGA proposal for the construction of six Tu-144s with updated NK-144A engines offering higher thrust and better fuel economy should be accepted. The design of these machines was to be updated with changes in the aerodynamics to achieve a maximum lift/drag ratio of 8 or better. This

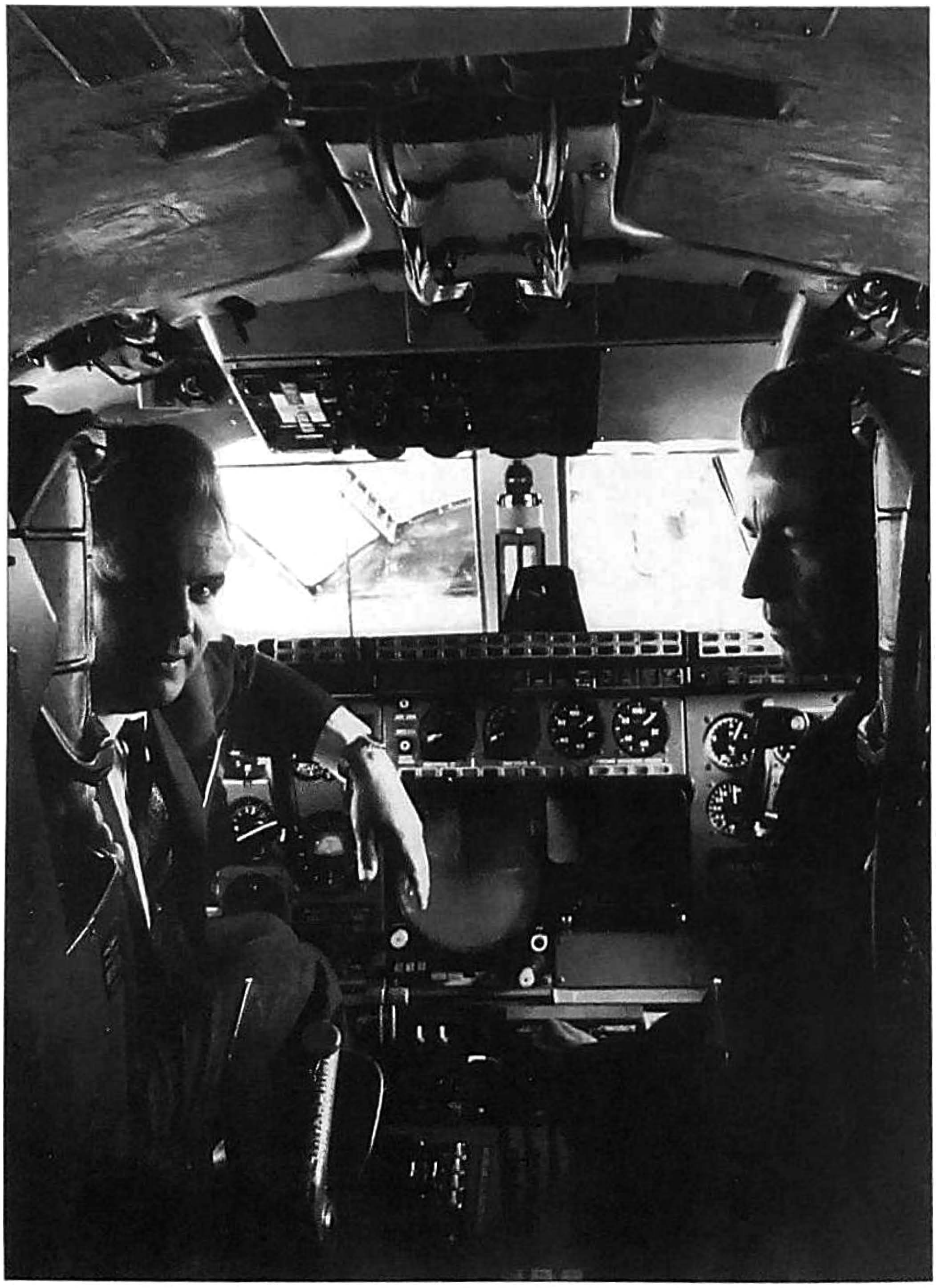


Above and below: Tu-144 CCCP-68001 is seen here during an early test flight with the nose up and the landing gear down, showing off its sleek profile. Note how the titanium elevons stand out against the grey-painted wings. MiG-21I CCCP-144 is flying chase; the camera ship was a Tu-124 airliner.





Above: Another shot of the Tu-144 prototype accompanied by the MiG-21I.



Captain Eduard V. Yelian (left) and co-pilot Mikhail V. Kozlov in the flightdeck of Tu-144 CCCP-68001 with the nose visor raised. Note the ejection hatches in the roof.

updating was designed to reach the first stage in achieving the necessary range of 4,000-4,500 km (2,480-2,795 miles). Later production versions were to be fitted with RD36-51 engines.

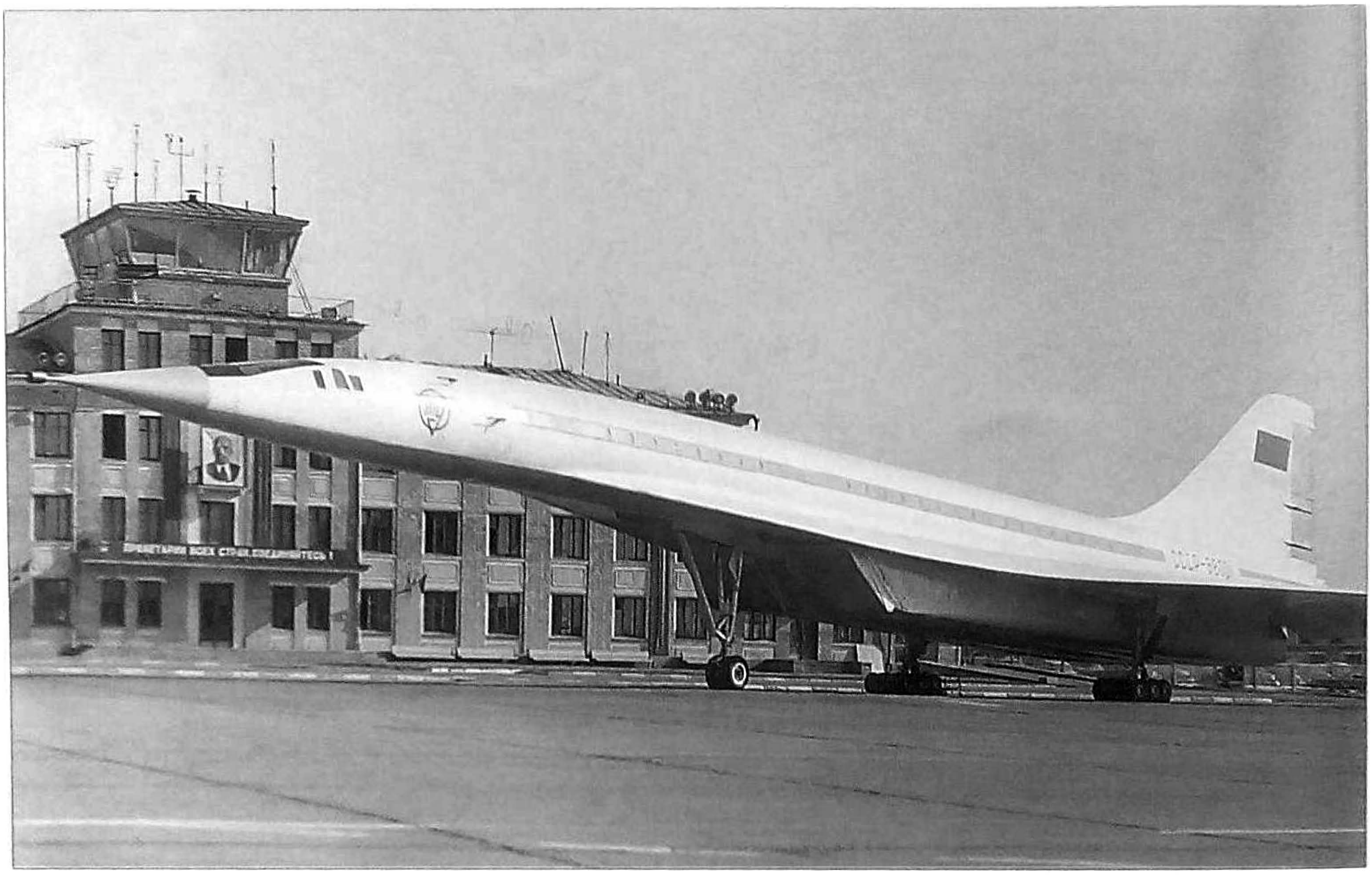
The resulting aircraft was different enough to warrant a new in-house product code, *izdeliye* 004; in fact, it was totally new from a structural standpoint. The fuselage was longer and featured a circular cross-section (the flattened underside and characteristic chines of the *izdeliye* 044 prototype were gone), and the shape of the drooping nose section housing the radar were altered. The cabin window arrangement changed from 25 windows on each side (door+8+door+ emergency exit (with a window) +6+exit+5) to 43 on each side (door+12+door+11+exit (windowless)+10+exit) The new wings had pronounced camber and a cranked leading edge instead of the prototype's smooth S-curve; the shape of the fin was similarly altered.

As mentioned in the previous chapter, to counter the pitch-down force created when the elevons were drooped, acting as flaps for take-off and landing, the wings were augmented by unique retractable canard foreplanes. These high aspect ratio aerodynamic surfaces of very small area were mounted on top of the forward fuselage just aft of the flightdeck, folding aft into a special fairing for cruise flight. When deployed, the canards had 15° anhedral and bristled with double-slotted leading-edge slats and double-slotted trailing-edge flaps deploying automatically as the canards unfolded.

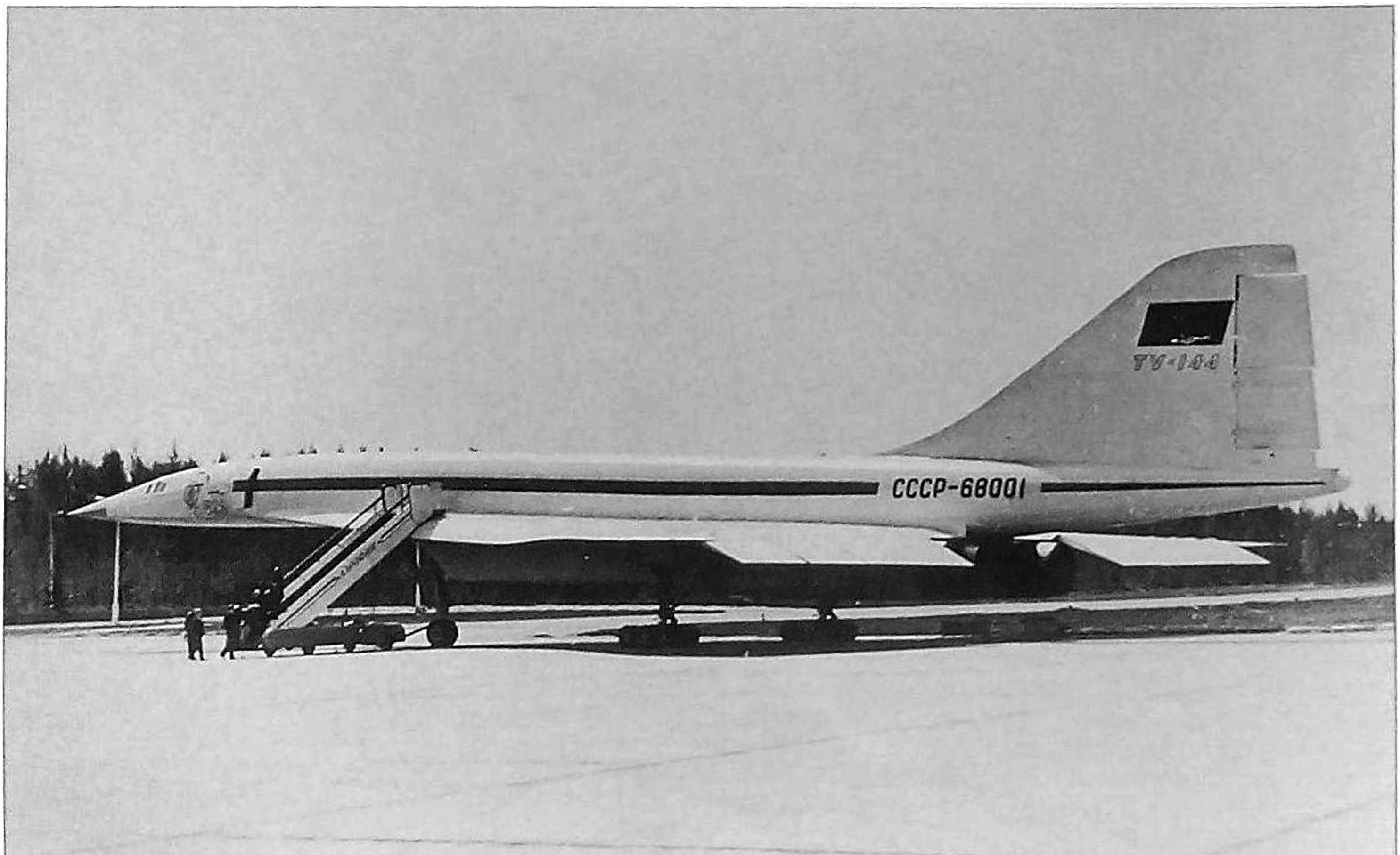
The Tu-144 (*izdeliye* 004) was powered by NK-144A turbofans uprated to 3,000 kgp (6,610 lbst) dry, 5,000 kgp (11,020 lbst) in minimum afterburner and 20,000 kgp (49,020 lbst) in full afterburner. The engines were now housed in paired nacelles located under the wing centre section, albeit rather closer to the fuselage than on the Concorde; additionally, the APU was relocated from the rear fuselage to the starboard engine nacelle. Finally, the landing gear was completely redesigned; the nose unit now retracted forward, while the main units were located underneath the engine nacelles, retracting into narrow wheel wells located between the inlet ducts of each pair of engines. Hence the number of wheels per bogie was reduced to eight (two rows of four) and the bogies now tipped up through 90°, inboard ends uppermost, prior to retraction. A retractable tail bumper was added.

The first of the 'second-generation' Tu-144s, CCCP-77101 (c/n 01-1), was again built by MMZ 'Opyt' in Moscow, making its first flight on 1st July 1977. The Tupolev OKB describes this aircraft as a pre-production machine rather than the second prototype. All subsequent examples were built by aircraft

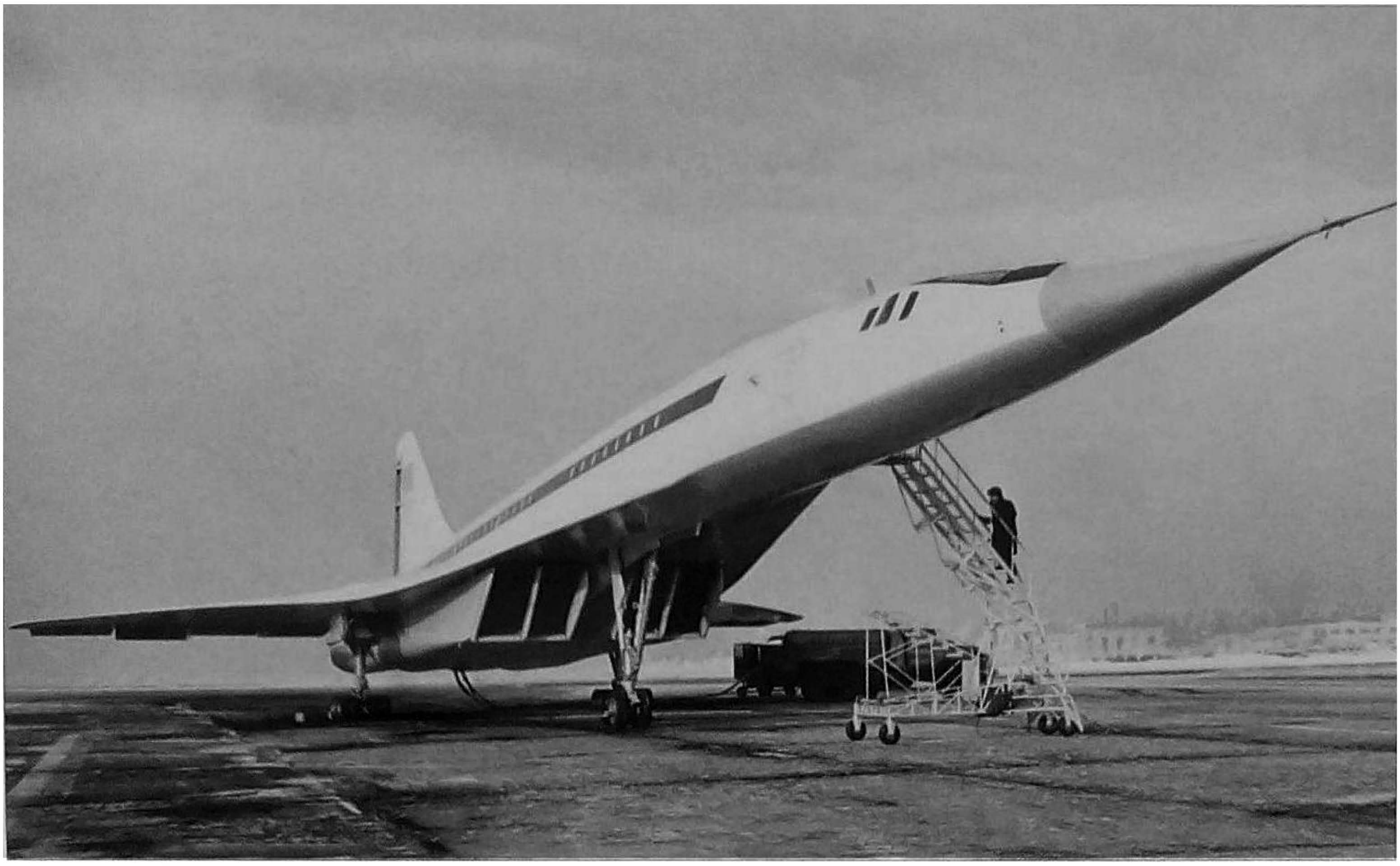
Aleksey A. Tupolev (centre) withe the test crew of Tu-144 CCCP-77101 after the first flight. Note the emergency escape hatch with faired hinges ahead of the forward entry door.



Above: The Tu-144 prototype in front of the old control tower on the north apron at Moscow-Sheremet'yevo (now Sheremet'yevo-1) during a publicity tour. Until the mid-1970s each of Aeroflot's types had its own livery.



CCCP-68001 parked at Moscow/Vnukovo-2, the government VIP apron. An SPT-104 gangway is parked near the closed rear entry door; the forward entry door is open a crack.



Above: CCCP-68001 is readied for a mission on a winter day; with no 'civilised' gangways within easy reach, anyone wishing to come aboard has to use a rickety work platform. A UPG-300 ground power unit based on a ZiL-131 6x6 lorry and what looks like a test equipment cart are connected to the aircraft.

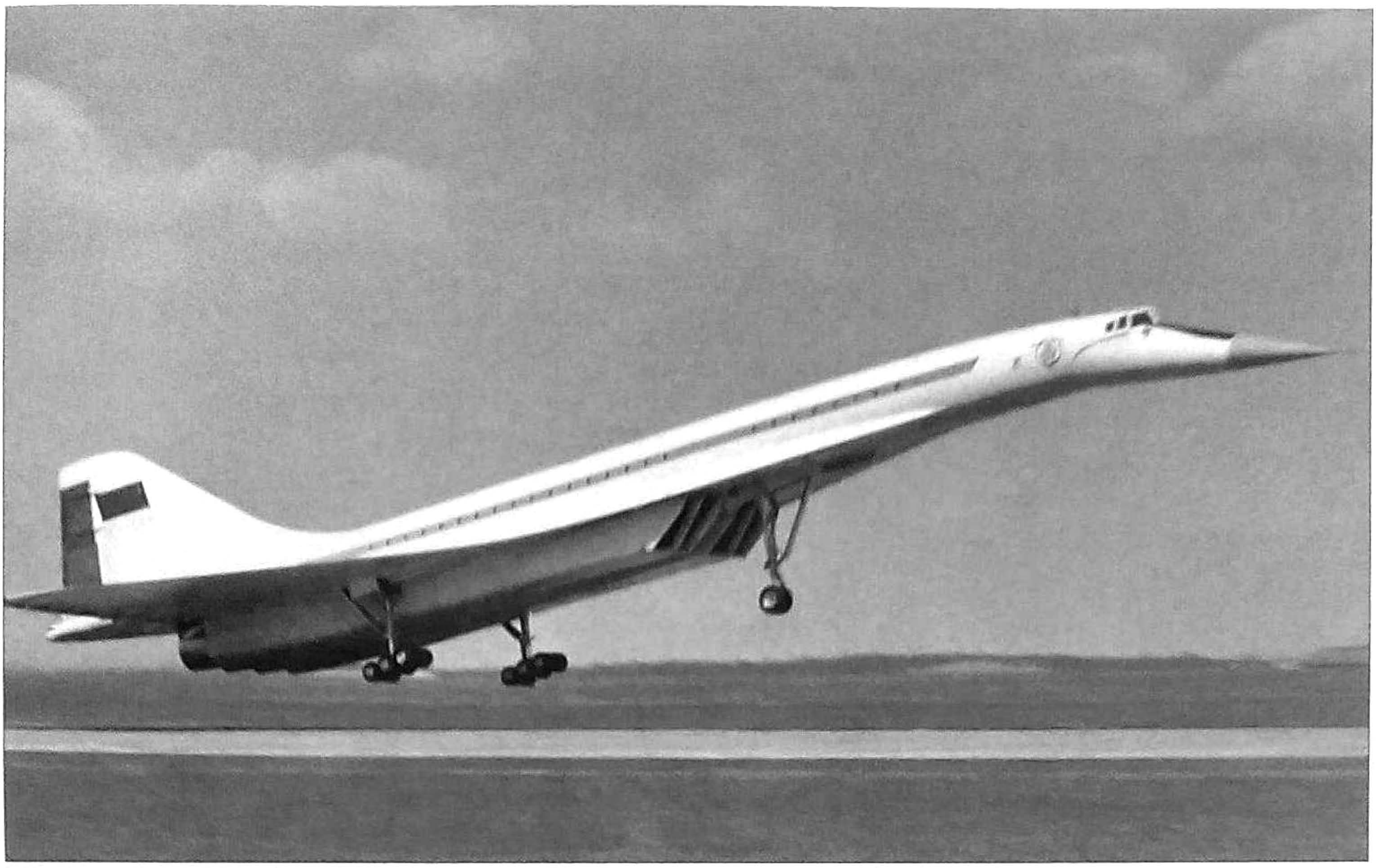
Here, the Tu-144 prototype with a KrAZ-214 6x6 heavy-duty lorry hooked up is again seen at Moscow/Vnukovo-2 with the government terminal in the background.

Above: Tu-144 models were used not only for tests but also as gifts, especially if presented by Andrey N. Tupolev himself.

factory No.64 in Voronezh, a series production plant. Hence the production version is sometimes referred to as the Tu-144S (*sereeynyy* – production, used attributively).

In keeping with well-established practice the tests of new Soviet commercial aircraft, just like those of military aircraft, were divided into several stages. Stage 1 normally commenced with the manufacturer's flight tests; their objective was to check the aircraft's behaviour, explore its flight envelope and verify the operation of the aircraft's systems and equipment before the next stage. Stage 2 was known as state acceptance trials (in effect, certification trials) and was held by the design bureau in close co-operation with the customer – in this case, the Ministry of Civil Aviation. During the trials the ministry was

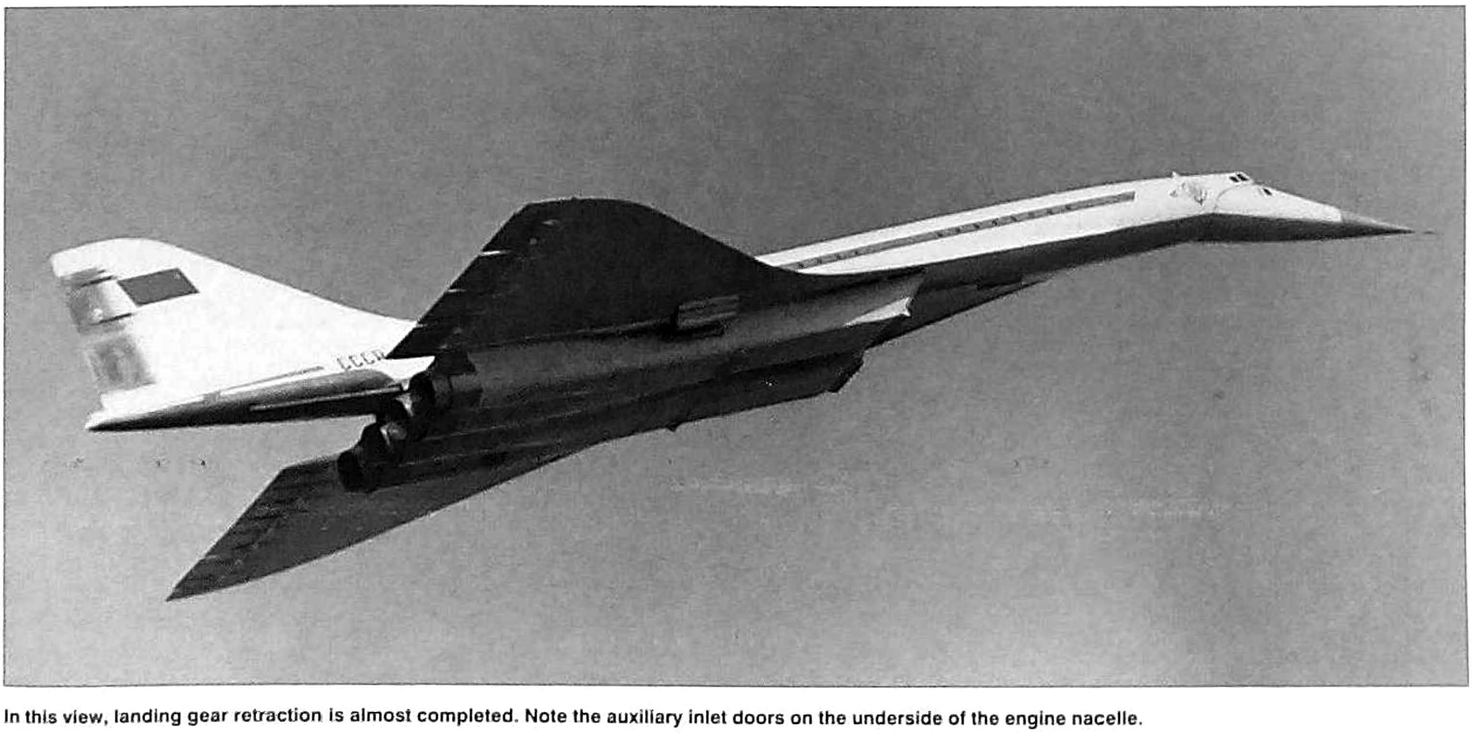
With a GAZ-69A jeep used as a ramp pilot vehicle (note whip aerial) hot on its heels, the Tu-144 is towed across runway 06/24 to the civil apron at Vnukovo-1. Note that the originally unpainted rudder has been painted white.



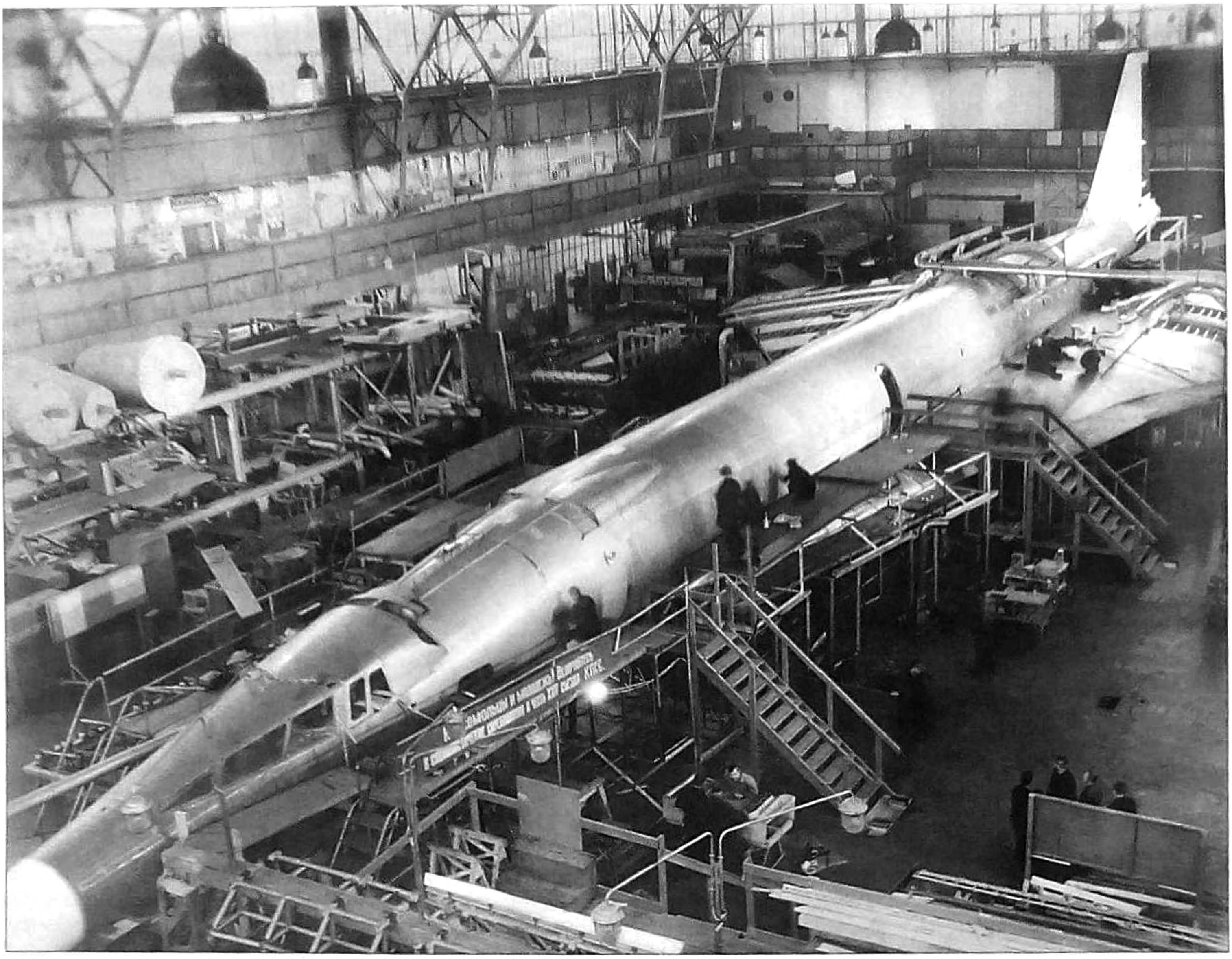
Above: The Tu-144 prototype seen a couple of seconds after becoming airborne.

represented by its research establishment, the State Civil Aviation Research Institute (GosNII GA – *Gosoodarstvennyy naoochno-issledovatel'skiy institoot grazhdahnskoy aviahtsii*) located at Moscow-Sheremet'yevo airport.

All stages of the Tu-144's test programme took place at the LII airfield in Zhukovskiy with the participation of the flight and ground personnel of the Tupolev OKB's flight test facility. Apart from the *izdeliye* 044 prototype (CCCP-68001), the following five Tu-144s (*izdeliye* 004) participated in the manufacturer's flight test stage: CCCP-77101 (c/n 01-1); CCCP-77102 (c/n 10012), the first production Voronezh-built Tu-144 *sans suffixe* which first flew on 29th March 1972; CCCP-77103 (c/n 10021) first flown on 13th December 1973;



In this view, landing gear retraction is almost completed. Note the auxiliary inlet doors on the underside of the engine nacelle.



A production Tu-144 takes shape at the Voronezh aircraft factory. The recess aft of the flightdeck where the foreplanes are to be installed can be seen, as can the different design of the nose visor glazing. The cabin windows are covered with protective paper for the time being to prevent scratches.

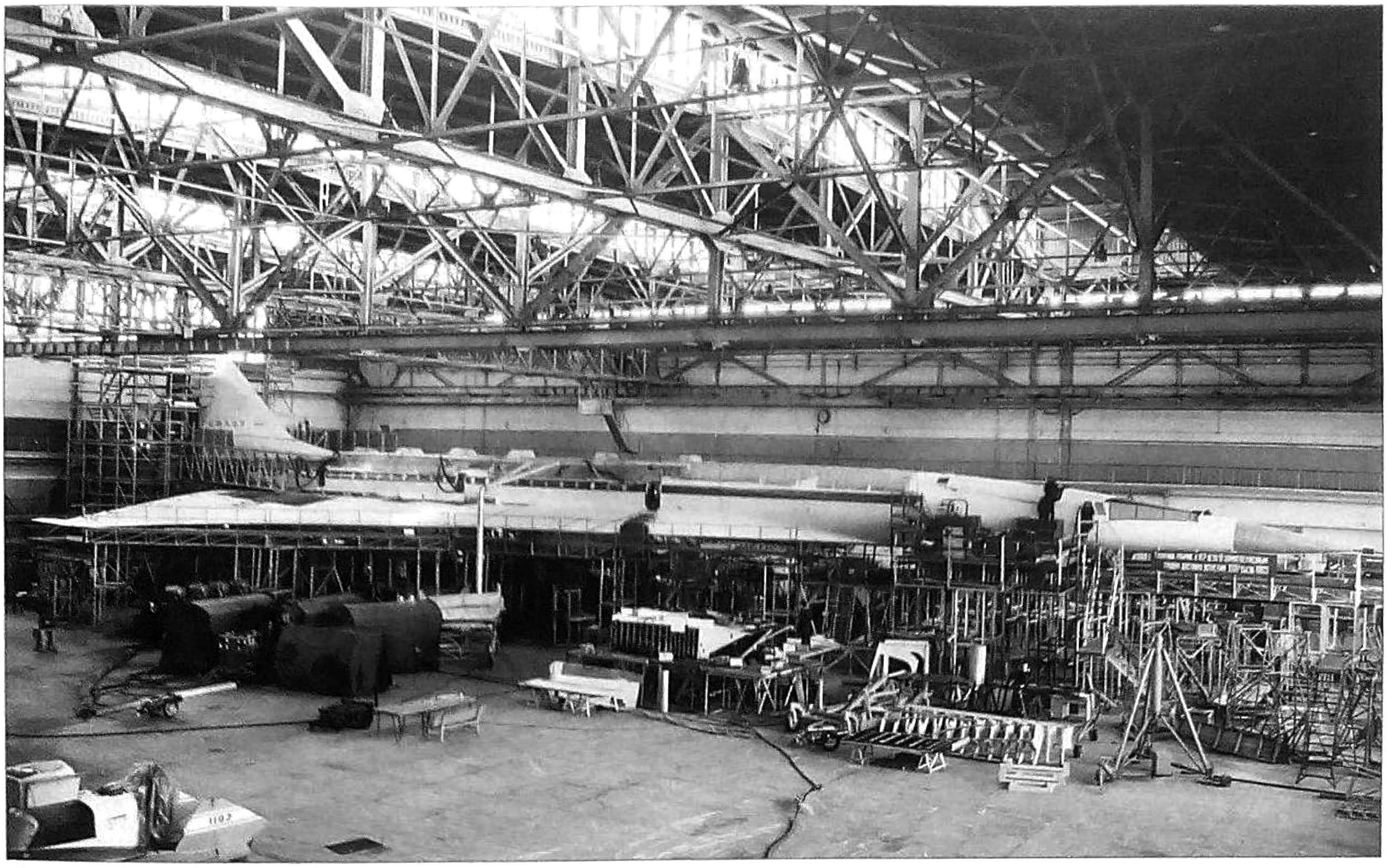
CCCP-77144 (out-of-sequence registration, c/n 10022) first flown on 14th June 1974; and CCCP-77106 (c/n 10041) first flown on 4th March 1975. Between them these six aircraft made a total of 462 flights at this stage of the programme. (It should be noted that, although the c/ns of production examples are often quoted in abbreviated form (for instance, 04-1), extended five-digit c/ns commencing 10... can be found in official documents; the 10 may be an internal product code at the factory.) CCCP-77106 differed from earlier Tu-144s in dispensing with the fixed trailing-edge portions outboard of the elevons, maximising the area of the latter.

It should be noted that the success of the trials hinged to a considerable degree on the human factor. It took dedication and initiative on the part of everyone involved to develop and test an aircraft of a completely new class within a very short time span. The tests were performed by several crews, each of which was a perfectly matched team consisting of highly experienced airmen and engineers. The flights were not altogether without incident, requiring the crew to keep their heads cool and putting their skill to the test. On one occasion two of the four engines failed on the way home after a publicity flight to Hannover, forcing the crew to make an emergency landing in Sofia; to make matters worse, part of the active runway at Vrazhdebna was unusable due to runway resurfacing work. The crew captained by Eduard V. Yelian and including project engineer V. N. Benderov coped admirably with this emergency, preventing any further damage to the aircraft.

Other Tupolev OKB flight test personnel participating in the Tu-144 programme included flight engineers B. P. Pervookhin and V. I. Koolesh. Project engineer V. N. Benderov contributed immensely to the task of organising the test programme, his unflagging enthusiasm inciting the other employees to work just as hard.

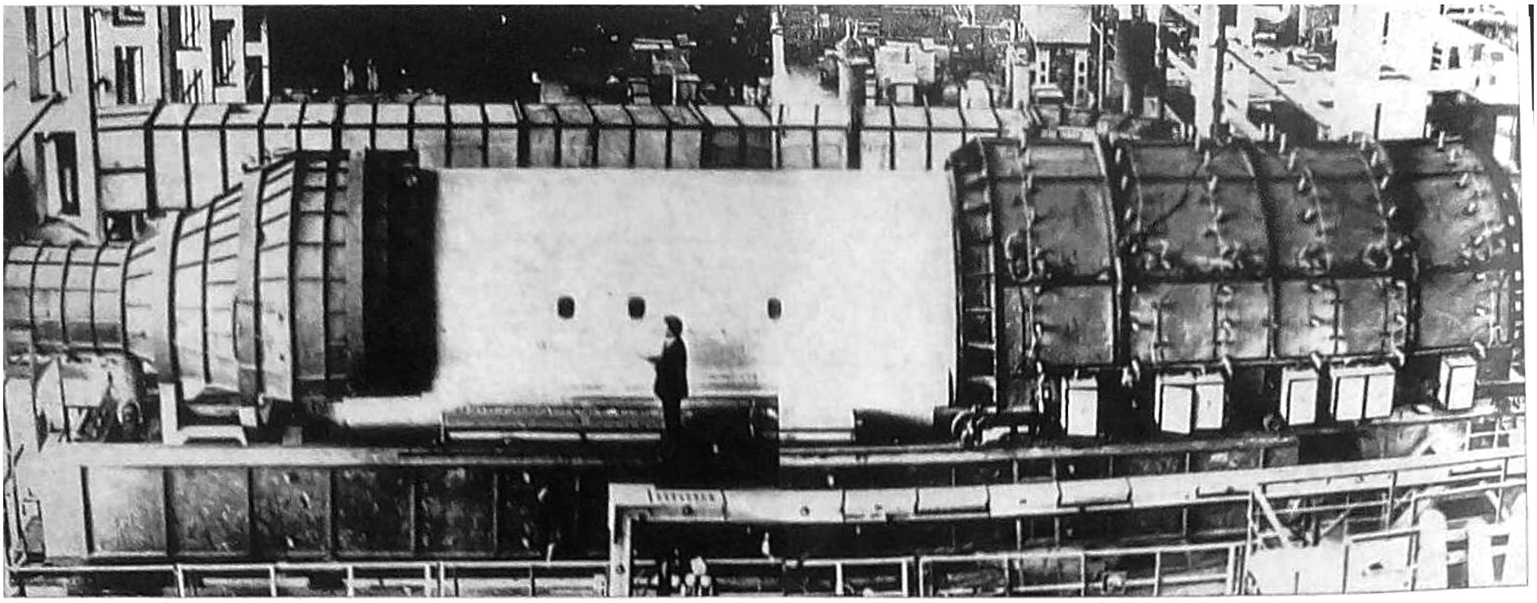
On 3rd June 1973 the Tu-144 programme suffered its first serious setback. The first production example (CCCP-77102) crashed in the Parisian suburb of Goussainville during a demonstration flight at the 30th Paris Air Show, and the true cause of the accident remains a mystery. After a series of very tight turns – the usual antics which airliners perform at airshows but not in real life – the Tu-144 climbed steeply, then inexplicably dived and broke up in mid-air when trying to recover, bursting into flames as it fell. The entire crew (captain M. V. Kozlov, co-pilot V. M. Molchanov, deputy chief designer V. N. Benderov, flight engineer A. I. Dralin, navigator G. N. Bazhenov and engineer B. A. Pervookhin) died on the spot.

An accident investigating panel consisting of Russian and French specialists was set up to determine the cause of the tragedy. The panel found no technical failing, but ascribed the accident to several human causes. These were the presence of unsecured members of the crew in the flightdeck, the unexpected appearance of a French Air Force Dassault Mirage III fighter in the pilots' field of view (the theory is that the fighter pilot came a bit too



Above: Tu-144 CCCP-77101 receives its coat of paint in the assembly shop of MMZ No.156 in Moscow. The object in the lower left-hand corner is another Tupolev product, the little-known A-3 amphibious aerosleigh.

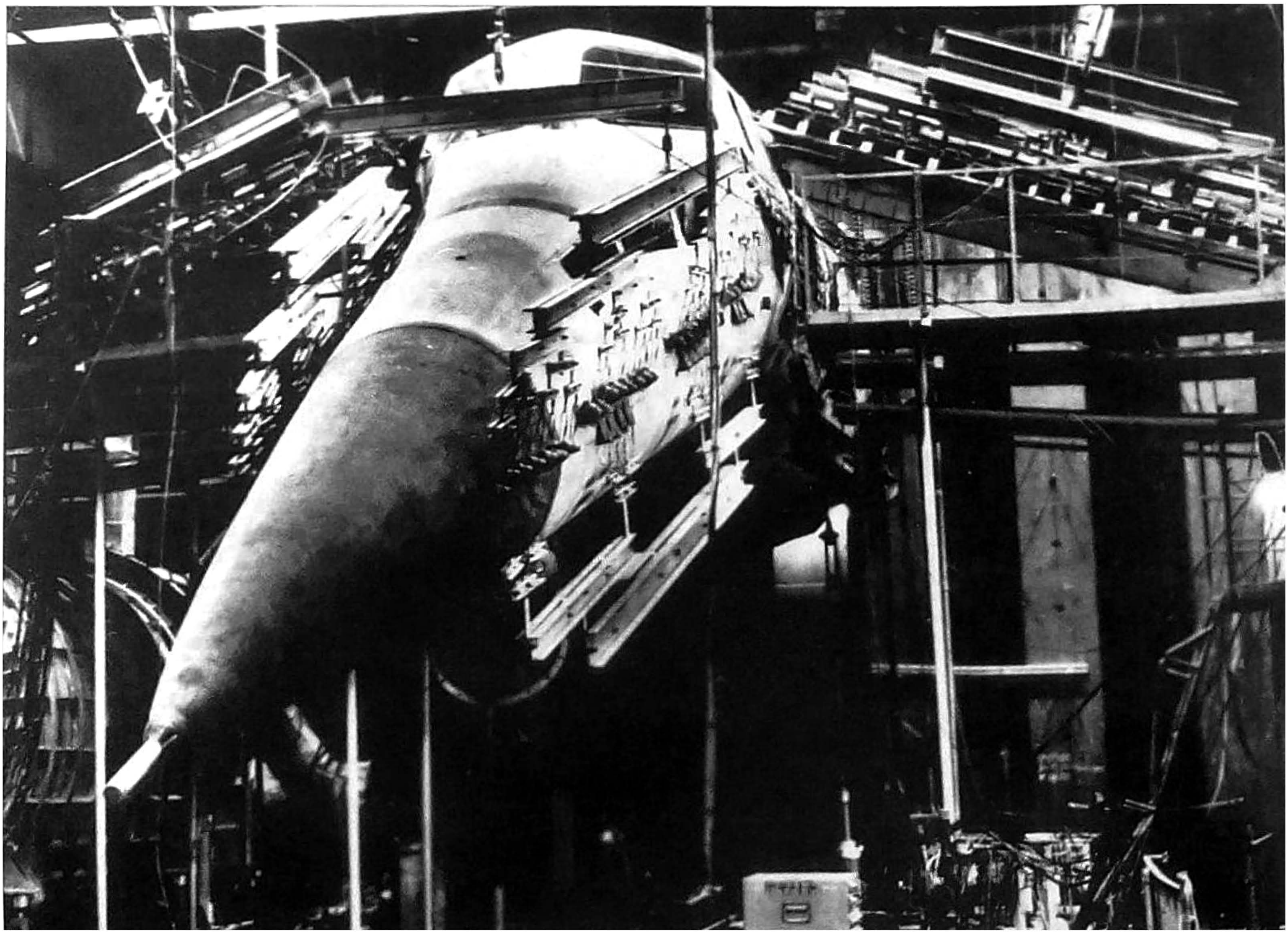
A foreign delegation escorted by MAP officials visits the Tu-144 final assembly line in Voronezh.



Above: A section of the Tu-144's fuselage undergoing static tests.

close to the Tu-144, the latter's pilots took violent evasive action and overstressed the aircraft), and the fact that one of the crew was holding a cine camera which might have fallen and become wedged against the control column. Taking all this into account, such a conclusion suited everyone. Eduard V. Yelian later commented in the 1990s that 'this catastrophe was a bitter reminder of how a number of what at first seem trivial acts of carelessness – in this instance by the French flight control – can have tragic consequences'.

State acceptance trials of the Tu-144 commenced in 1975 in keeping with a joint MAP/MGA ruling 'On the service introduction of the Tu-144 supersonic airliner with NK-144 engines'; this document also set out the trials schedule. The integrated trials programme



A complete Tu-144 (*izdeliye* 004) airframe rigged for static tests.

consisted of two stages; Stage A was intended to determine the possibility and conditions of mail and cargo carriage, while Stage B was aimed at full certification for passenger operations.

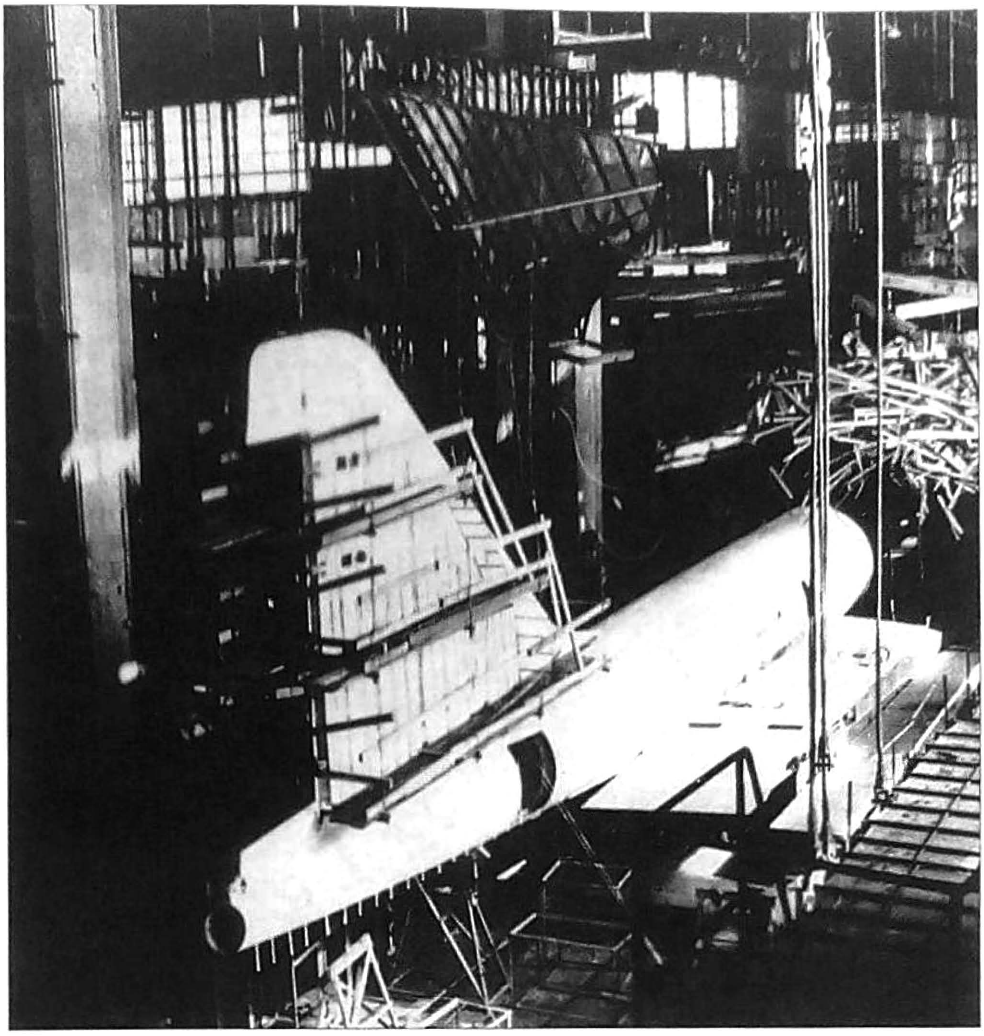
Six aircraft were involved in this phase of the programme. CCCP-77101 served for powerplant testing and aborted take-off tests, CCCP-77103 was used for verifying the navigation suite and the electric system, CCCP-77144 served for aerodynamic, structural strength and high-angle-of-attack tests, and CCCP-77106 was used for route proving flights by Aeroflot. The other two aircraft were new to the test fleet; CCCP-77108 (c/n 10042) first flown on 20th August 1975 served for testing the flight director landing approach mode, the automatic flight control system (AFCS) and autothrottle, while CCCP-77107 first flown on 12th December 1975 (c/n 10051; the registration sequence was reversed) served for integrated evaluation of the aircraft and its systems and defining the basic type to be certified.

According to the test schedule the state acceptance trials were due to be completed in the third quarter of 1976, the service evaluation period ending shortly afterwards in October, whereupon scheduled passenger flights were to commence in November. All in all, the six Tu-144s participating in the certification trials made 976 flights between them.

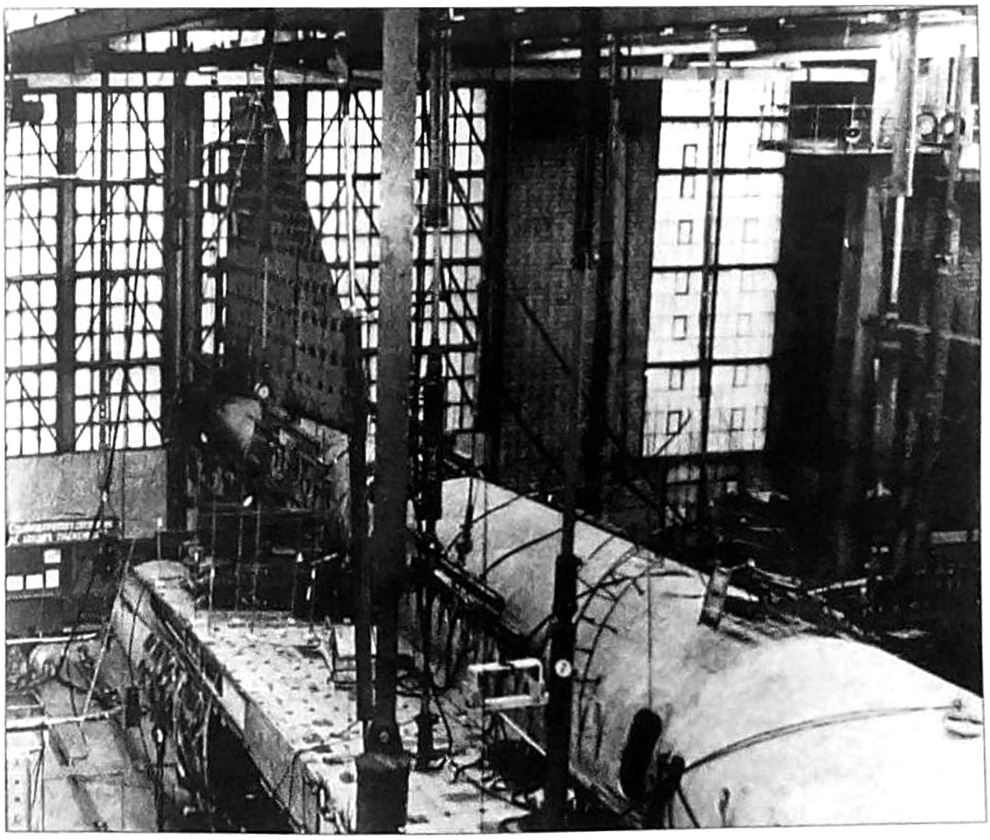
On 26th December 1976 Tu-144 CCCP-77106 commenced operational trials on Aeroflot's Moscow – Alma-Ata service, carrying freight and mail. Besides familiarisation, these flights were meant to check the aircraft for compatibility with Aeroflot's existing ground support systems and logistics schemes. Additionally, the KKO-OS-1 breathing apparatus for the crew was tested and ground noise measurements/sonic boom assessments were made during these route proving flights.

The flying personnel and ground specialists of GosNII GA participated in the joint state acceptance/certification trials from beginning to end. The trials programme and all associated activities were co-ordinated by the state acceptance trials commission chaired by I. S. Razumovskiy.

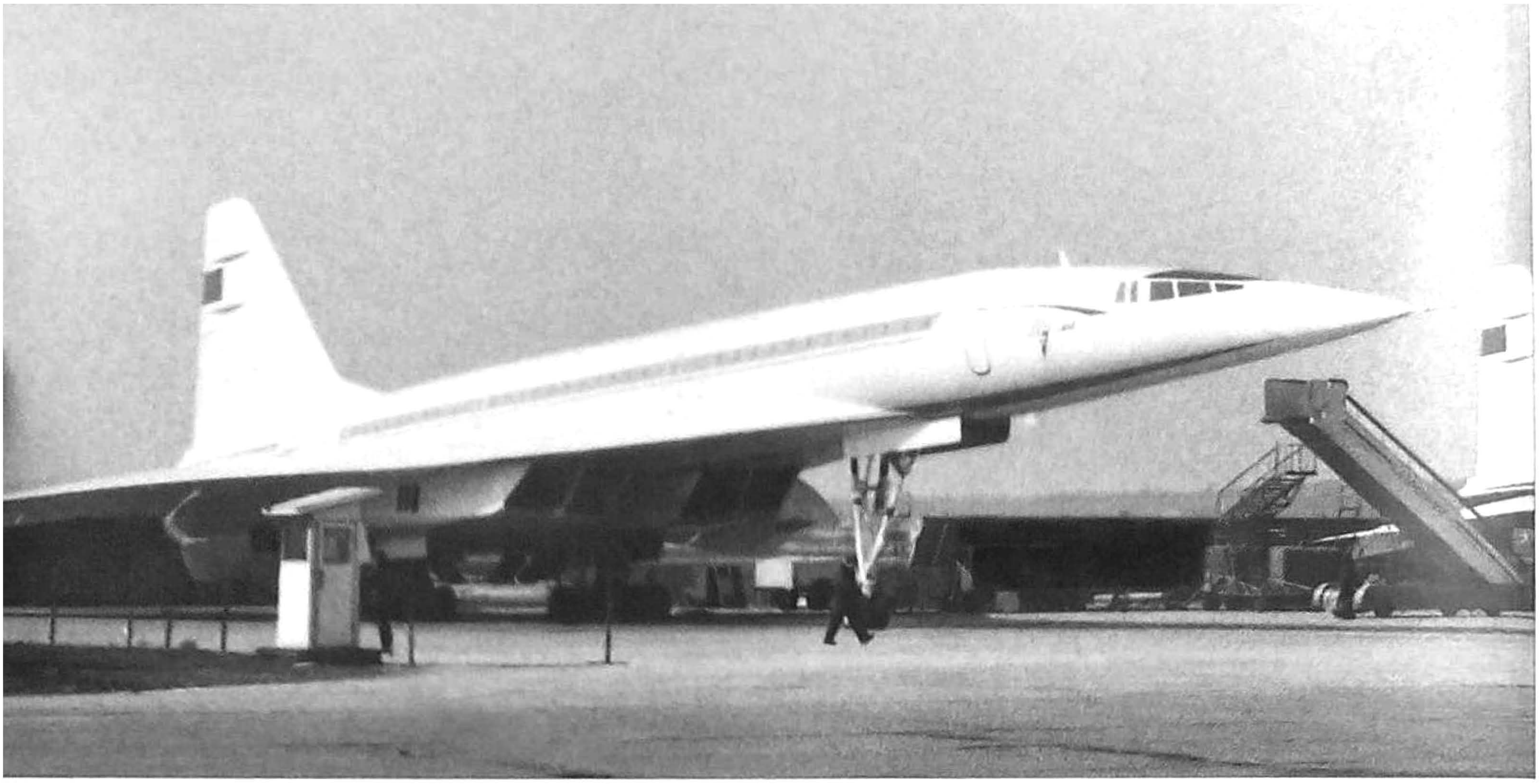
Hard though the Tupolev OKB and GosNII GA tried, the trials schedule kept slipping. The main reason was that the integrated evaluation airframe (CCCP-77107) underwent continual changes and was not ready for certification in the intended baseline configuration until October 1976. Similarly, the next two Tu-144s *sans suffixe* earmarked for route proving trials – CCCP-77109 (c/n 10052) and CCCP-77110 (c/n 10061) were completed late, making their first flights on 29th April 1976 and 14th February 1977 respectively, and were ready for testing in May 1977 rather



Above: The rear fuselage, fin and wing centre section of the Tu-144 (*izdeliye* 004) structural test article (c/n 01-4). Note the open rear baggage door.



Static testing is in progress on Tu-144 c/n 01-4.



Above: The pre-production Tu-144 (CCCP-77101) parked with the nose raised in company with a production example. Note the bold nose titles. The production model had a slightly bigger nose-up ground angle than the prototype.

than December 1975 as planned. These serious delays were largely accounted for by the difficulties in mastering the new technologies used for manufacturing the airframe, systems and engines. Inevitably, the test flights revealed defects and bugs which had to be eliminated, and that took time.

Between 24th September and 22nd October 1977 Aeroflot undertook operational trials of Tu-144s CCCP-77109 and CCCP-77110.

The Soviet Union was rather tardy in adopting airworthiness regulations and compulsory certification procedures for commercial aircraft (the first Soviet airworthiness regulations for fixed-wing aircraft came into effect in 1967). The first Soviet airliner to receive a 'normal' type certificate – the Tu-134A short/medium-haul twinjet – had been certificated abroad. Thus, it so happened that the Tu-144 became the first Soviet commercial aircraft to be certificated in its home country. Small wonder that the certification procedure was arduous.

The Soviet Union's Inter-Department Airworthiness Regulations Co-ordinating Commission (MVK NLGS – *Mezh**ved**omstvennaya **kom**issiya [po soglasova**n**iyu] norm **lyot**noy **god**nosti samo**lyo**tov*) and the State Aircraft Register were instructed to draw up provisional airworthiness regulations for super-

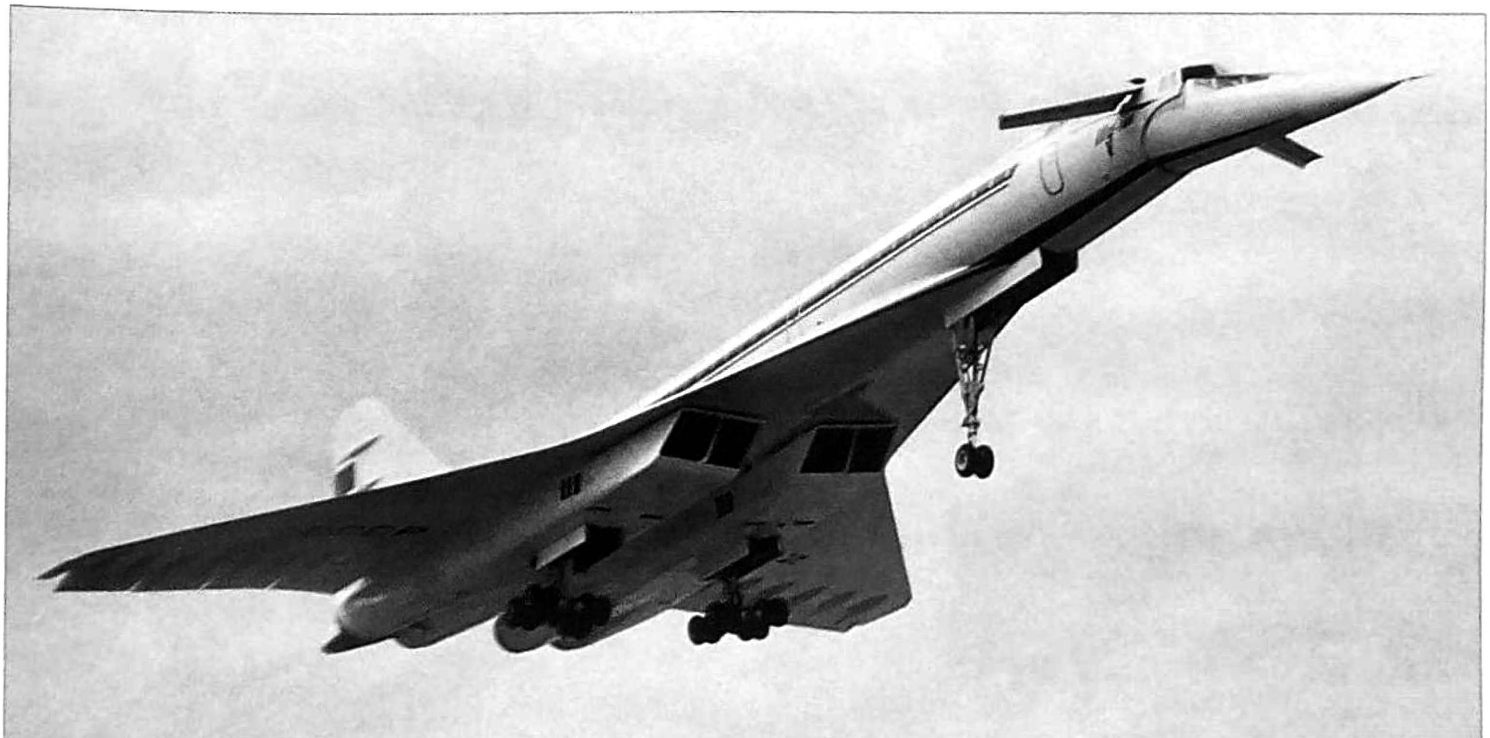
Another view of CCCP-77101. Note the deflected lower half of the rudder.

Above: This view of CCCP-77101 shows the phototheodolite calibration markings applied to the fuselage in line with the emergency exits and the full-span elevons. Note that originally the Aeroflot titles were carried in small type on the fin and the registration was painted on the fuselage (in a gap in the cheatline).

sonic aircraft (VNLGSS – ***Vre****mennyye* ***nor****my* ***lyot****noy* ***god****nosti sverkhzvooko****vykh*** *samo-****lyo****tov*) and submit them for approval by 1st May 1975. The VNLGSS became effective on 11th September 1975. Considering that the Tu-144's joint state acceptance trials ordered by MAP and MGA had begun in April 1975 when the said regulations were not yet in effect, imagine the huge scope of certification work that had to be performed in parallel with the trials. The Flight Research Institute provided invaluable assistance to the Tupolev OKB at this stage.

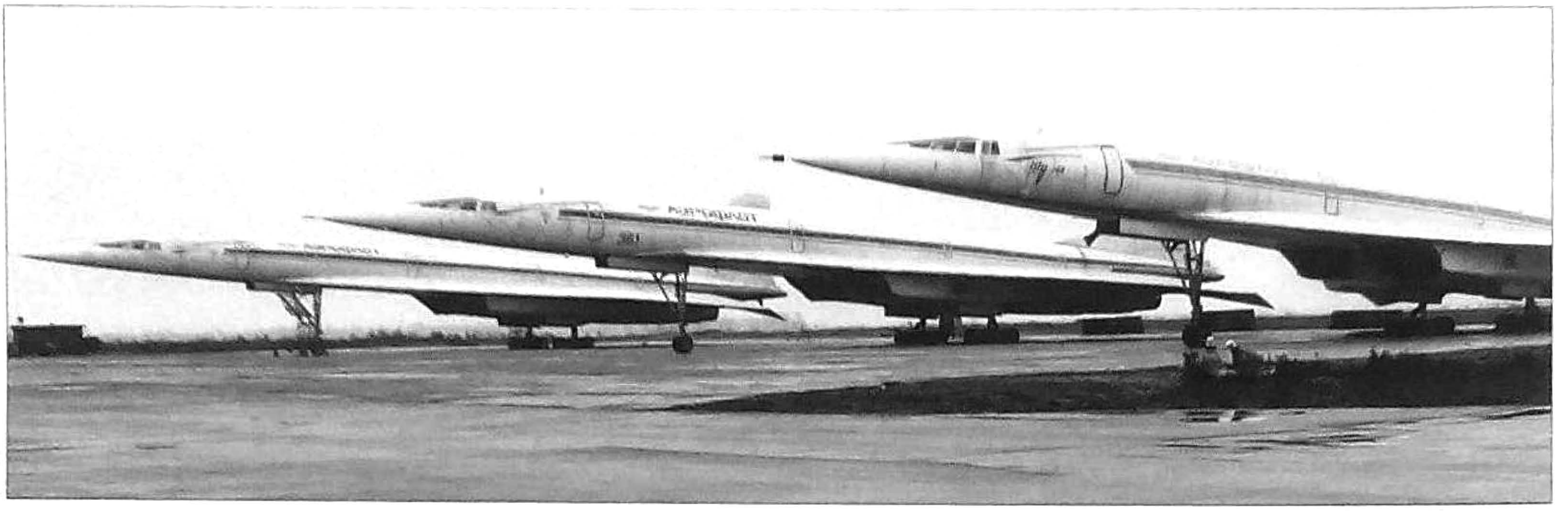
The state acceptance trials and certification tests showed that the Tu-144, its powerplant and systems met the stipulations of the VNLGSS on 1,620 counts. The amount of documents produced during the trials to prove its compliance to the standard was in excess of 2 m³ (70.6 cu ft).

The joint state acceptance/certification trials of the NK-144A powered version were finally completed on 15th May 1977. For some reason, though, Minister of Aircraft Industry Pyotr V. Dement'yev and Minister of Civil Aviation Boris P. Boogayev did not endorse the trials protocol until 13th September 1977 (so much for superstition, eh?). Among other things, the document said: 'The process of developing the first indigenous



Tu-144 CCCP-77102 seen on final approach with the canards deployed. Note how the mainwheel axles are at right angles to the outward-canted main gear oleos in no-load condition.

Above: These two Tu-144s (izdeliye 004) in 'happy' and 'sad' configuration make an interesting comparison with the original prototype on the right.
Below: A trio of Tu-144s in Zhukovskiy illustrates the difference between the old (foreground) and the new versions of the production version's Aeroflot livery.



Aleksey A. Tupolev (second from right) and other Tupolev design staff members with the Tupolev OKB's test pilots at Sofia-Vrazhdebna. Note the exhibit code 826 which CCCP-68001 had worn at the 1969 Paris Air Show.

supersonic airliner, the Tu-144, has made it possible to tackle a large number of hitherto unseen and complex engineering problems, evolve a number of advanced design features and technologies. It has yielded a wealth of experience in testing and refining supersonic airliners.'

On 30th September the State Aircraft Register issued Provisional Type Certificate No.02V-004 to the production Tu-144 *sans suffixe* (the V stood for ***vrem****ennyy* – temporary or provisional, while the 004 denoted *izdeliye* 004). The proper type certificate was issued on 29th October 1977, when the Tu-144 had completed its service evaluation programme and the appropriate protocol had been signed.

Presently the Ministry of Aircraft Industry and the Ministry of Civil Aviation decided that scheduled passenger services could be launched. Accordingly, on 31st October 1977 the two ministers signed an appropriate order (No.173-269) clearing the Tu-144 for its commercial operations on the Moscow – Alma-Ata service. The first revenue flight took place the following day, on 1st November, with a crew that was a mix of MAP and Aeroflot personnel at the controls.

Tu-144D Supersonic Airliner (Production Version, *Izdeliye* 004D)

Work on the Tu-144 with Kolesov RD36-51 engines began as early as 1964. On 4th June 1969 the VPK passed Ruling No.131 concerning the Tu-144 with RD36-51 engines. Its range was set at 4,500 km (2,795 miles) with a take-off weight of 150 tons (330,690 lb) and 150 passengers, or 6,500 km (4,040 miles) with 120 passengers and a take-off weight of 180 tons (396,825 lb). This version with the new engines was designated Tu-144D or *izdeliye* 004D (***dahl'****neye* – long-range).

Presently, when the RD36-51A non-afterburning turbojet had passed its bench and flight test programme in the mid-1970s, the go-ahead was given to install the new engines in the Tu-144. The RD36-51 had a take-off thrust of 20,000 kgp (44,090 lbst), a maximum cruise thrust of 5,100 kg (11,240 lbst) and a specific fuel consumption of 1.26 kg/kgp·hr in supersonic cruise. OKB-36 planned to increase the take-off thrust to 21,000 kg (46,300 lbst) and attain a cruise SFC of 1.23 kg/kgp·hr. Beyond that it was hoped to achieve a take-off thrust of 23,000-24,000 kgp (50,700-52,910 lbst) and a cruise thrust of 5,400 kgp (11,900 lbst).

The first Tu-144 to receive the RD36-51A engines was CCCP-77105 (c/n 10031), which was built as a Tu-144 *sans suffixe* but converted straightaway as the Tu-144D prototype. It first flew on 30th November 1974. Outwardly the Tu-144D was readily identifiable by the new engine nozzles which had cropped conical centrebodies; the latter were translating (that is, moving fore and aft) for the purpose of adjusting the nozzle area in lieu of the usual nozzle petals. Also, the fixed wing trailing edge outboard of the outer elevon sections was reinstated.

On 5th June 1976 the aircraft covered a distance of 6,200 km (3,850 miles) with a payload of 5 tonnes, confirming the present and the future prospects in continuing work on the Tu-144D.

The tests proceeded with a good deal of trouble, as the new engines were in short supply; moreover, the first production RD36-51As had an extremely short service life. Debugging and perfecting the engine proved to be a lengthy affair, and the first RD36-51As in state acceptance trials configuration did not become available until late 1978. From then on the prototype was joined by five production machines – CCCP-77111 (c/n 10062,

Here, Aleksey A. Tupolev (third from left) and Bulgarian leader Todor Zhivkov (fifth from left) appear to be engaged in a heated dispute, gesturing emphatically, much to the amusement of the onlookers.

Above and below: The first production Tu-144, CCCP-77102, in company with the prototype. Note how the cheatline terminates short of the forward pair of doors. In this version of the livery, Aeroflot titles were normally carried on the tail only (CCCP-77101 was an exception to the rule).

manufactured on 18th April 1978), CCCP-77112 (c/n 10071, manufactured on 19th January 1979), CCCP-77113 (c/n 10081, first flown on 2nd October 1979), CCCP-77114 (c/n 10082, first flown on 13th April 1981) and CCCP-77115 (c/n 10091).

The availability of production Tu-144Ds seemed to indicate that the programme would now proceed at a steady pace. However, on 23rd May 1978 disaster struck again. During a routine test mission on CCCP-77111 a fatigue crack in a fuel line caused a fuel leak; when the APU was started up as envisaged by the flight plan, a massive fire ensued. MGA test pilot B. Popov and co-pilot Eduard V. Yelian managed to effect a wheels-up landing in an open field near Yegor'yevsk, Moscow Region, but Yelian was badly injured and the two test engineers sitting in the forward cabin lost their lives when the deflected nose visor dug into the ground, broke away and punctured the fuselage exactly where they sat. By then CCCP-77111 had logged only 9 hours 02 minutes; this was the aircraft's sixth flight.

All scheduled Tu-144 passenger flights were immediately suspended. This time the cause was traced with absolute certainty to a design flaw in the fuel system that was easy to rectify. However, the Tu-144, whose reputation had already been damaged by the 1973 Paris crash, had its share of detractors. Now, armed with a perfectly legitimate pretext, the anti-Tu-144 lobby charged to the attack, branding the aircraft as unsafe and demanding the termination of the programme. There were other incidents, too, which did not speak in favour of the Tu-144. On 31st July 1978 CCCP-77113 suffered a compressor disc failure in supersonic flight; the crew managed to decelerate and land the machine safely at Engels-2 airbase (a heavy bomber base) where it was repaired on site.

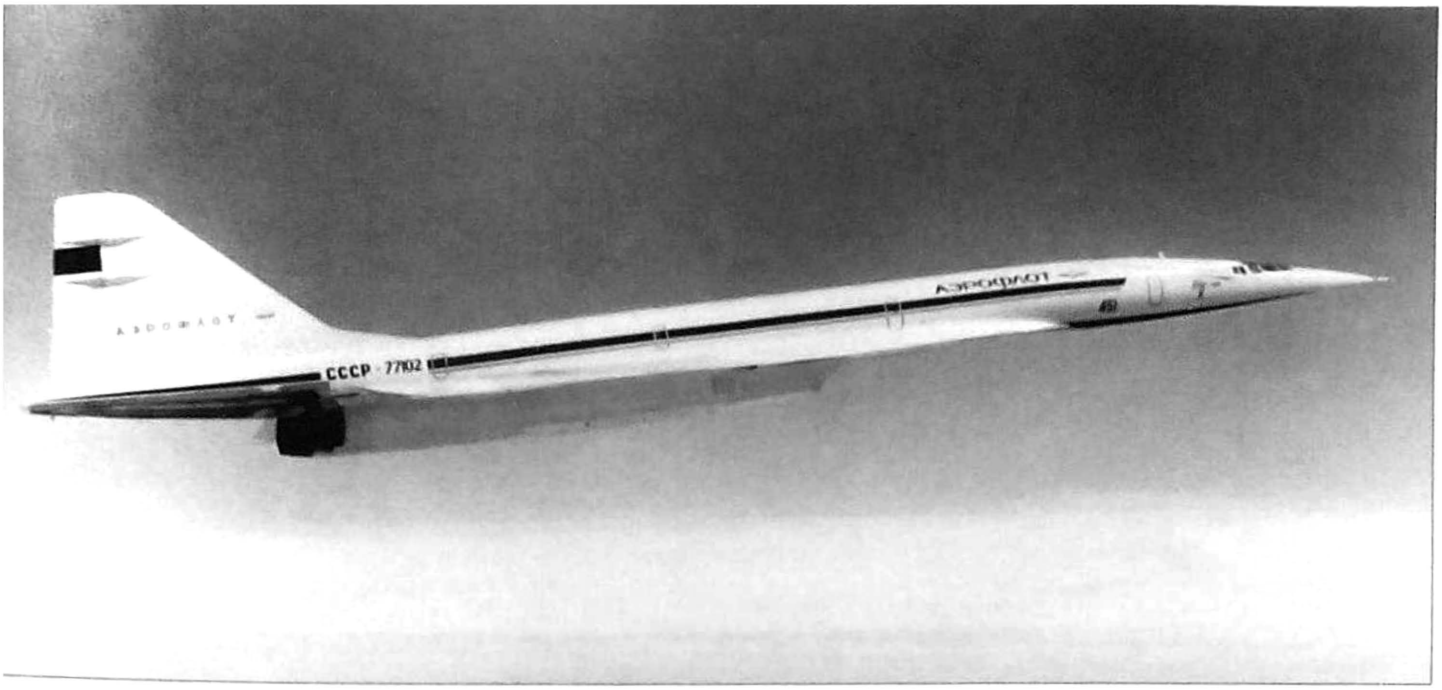
OKB-36 embarked on a series of measures aimed at improving the engine's reliability. The work continued until May 1981, whereupon the Tu-144D was submitted for state acceptance trials and formally accepted for these by MGA on 11th May. The greater part of the trials programme had been completed by the end of that year. Still, engine reliability problems persisted – albeit not necessarily with disastrous consequences. On 5th October 1981 CCCP-77112 (using the ATC callsign CCCP-77339) made a precautionary landing at Alma-Ata airport due to a false fire warning in the No.4 engine.

In the course of the state acceptance trials the Tu-144Ds performed a total of 411 flights, logging 764 flight hours. The aircraft showed the following basic performance:

Cruising speed	Mach 2.0
Effective range with 10-ton (22,045-lb) fuel reserves:	
with an 11 to 13-ton (24,250 to 28,660-lb) payload	5,700-5,500 km (3,540-3,416 miles)
with a 15-ton (33,070-lb) payload	5,330 km (3,310 miles)
with a 7-ton (15,430-lb) payload	6,250 km (3,880 miles)
Service ceiling	16,000-18,000 m (52,490-59,055 ft)
Maximum take-off weight	207 tons (456,350 lb)
Maximum landing weight	125 tons (275,570 lb)

In conformity with the State Aircraft Register's demands the Tupolev OKB began certification tests of the Tu-144D in parallel with the manufacturer's flight tests (the latter mostly took place in 1978-81). On 20th February 1981 LII issued a report stating the Tu-144D's conformity to the VNLGSS regulations. On 9th June 1981 the Tu-144D received a Provisional Type Certificate but was never put into service and the programme was gradually run down, officially because of the protracted development of the RD36-51 engines. The last Tu-144D, CCCP-77116 (c/n 10092), was not completed and sat on the factory airfield (Voronezh-Pridacha) for a long time. The others were retained by the OKB and used for test and research purposes (for instance, CCCP-77113 was used for atmospheric ozone research, helping to fight ozone layer depletion).

In July 1983 Tu-144D CCCP-77114 piloted by captain Sergey Agapov and co-pilot Boris Veremey set 13 world records for speed and altitude with different loads. The aircraft was notified to the FAI as the '101' and wore appropriate nose titles.



Above: The ill-fated CCCP-77102 with the exhibit code 451 applied for the 1973 Paris Air Show at which it was lost.

Tu-144DA Supersonic Airliner (Project)

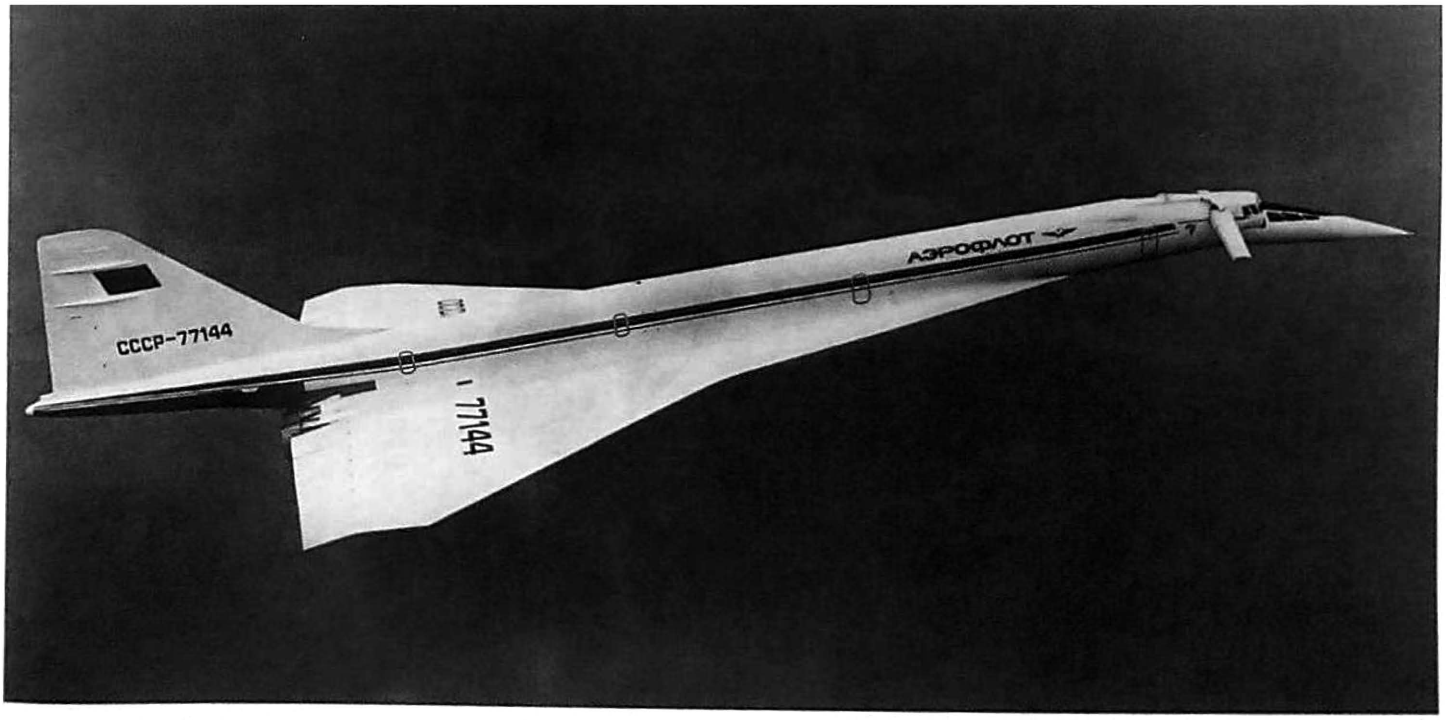
The 1970s saw new projects to update the Tu-144, the Tu-144D having proved that it could meet range requirements and had the potential for future development. Changes to the airframe, systems and equipment would allow greater fuel capacity. This new project was designated Tu-144DA.

Early studies along these lines indicated that, with a take-off weight of 235 tons (518,080 lb), the fuel load could be increased to 125 tonnes (275,570 lb) as opposed to 90-95 tons (198,410-209,435 lb) on the Tu-144D. The wing area was to be increased from 507 m^2 (5,451 sq ft) to 544 m^2 (5,849 sq ft). 'Type 61' engines (a derivative of the RD36-51A) with thrust reversers, a cruise SFC of 1.23 kg/kgp·hr and a take-off thrust of 21,000 kgp (46,300 lbst) were used. The number of passengers would be increased to 130-160 and range with a normal payload extended to 7,000-7,500 km (4,350-4,660 miles). No further work was done on the Tu-144DA due to the closure of the Tu-144 programme, but the project work was drawn upon during early research on the SST-2 (Tu-244).

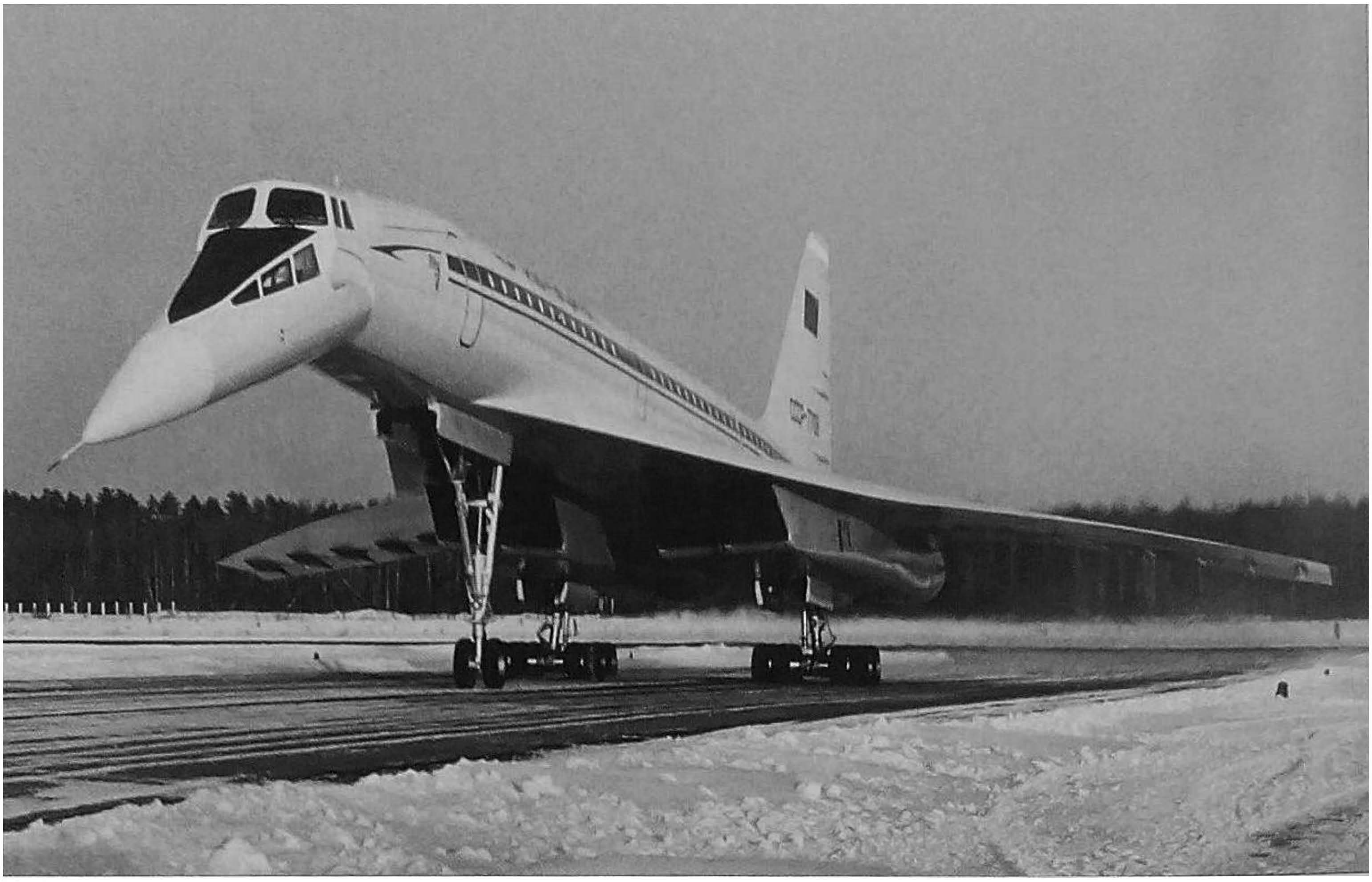
The Tu-144 in Aeroflot Service

Having no prior experience with SSTs, Aeroflot had to turn to the Tupolev OKB for help. Thus, day-to-day operation of the Tu-144s in the Moscow Transport Civil Aviation Directorate's Domodedovo United Air Detachment was performed by MAP technical staff assisted by Aeroflot staff; the idea was that the Aeroflot personnel would gradually take over as experience was built up and more personnel was trained.

As already mentioned, the first revenue flight of a Tu-144 took place on 1st November



An interesting shot of CCCP-77144 with elevons in flap mode and the canards out but with the landing gear retracted, probably in order to formate with a slow camera ship. Note the revised livery with extended cheatline and bolder titles. The registration on the tail is a custom one (it should have been CCCP-77104).



Above: CCCP-77106 leaves one of the runways at Moscow-Domodedovo after a flight from Alma-Ata.

Preparations for the Tu-144's inaugural passenger service from Moscow-Domodedovo to Alma-Ata.

Above: A fine perspective of an operational Moscow Transport Civil Aviation Directorate/ Domodedovo United Air Detachment Tu-144, CCCP-77109, from under the nose of a sister ship with Tu-134As, Tu-114s and an An-12 lined up beyond and Domodedovo's terminal and tower in the background.

Right: CCCP-77109 commences its take-off run.

Top: CCCP-77115 sits on a snow-covered Tupolev OKB hardstand at LII in company with a Tu-95MS bomber used in trials programmes.
Above: The same aircraft in a summer setting.

1977. So great was the significance of the event that General Designer Aleksey A. Tupolev, Minister of Aircraft Industry Pyotr V. Dement'yev, Minister of Civil Aviation Boris P. Boogayev and the top brass from both ministries came flocking to Moscow-Domodedovo to witness it. When the 80 passengers had taken their seats, the aircraft's captain, Merited Civil Aviation Pilot Boris F. Kuznetsov reported to Boogayev that the aircraft and the crew were ready to fly. After the usual pre-flight procedures had been carried out, Tu-144 CCCP-77109 became airborne at 09:03 hours Moscow time, touching down at Alma-Ata airport exactly two hours later. The return flight departed Alma-Ata at 13:28 hours and touched down at Domodedovo at 15:31 hours.

New lines reading *'Flight No.499 Moscow – Alma-Ata, departure 08:30 hours'* and *'Flight No.500 Alma-Ata – Moscow, departure 15:30 hours'* appeared in the timetable at Moscow-Domodedovo. At the service introduction stage these flights covering a distance of 3,260 km (2,024 miles), at an altitude of 16,000-17,000 m (52,490-55,770 ft) and at a speed of 2,000 km/h (1,240 mph) took place once a week. It should be noted that the Tu-144 was popular with the passengers and the flights were almost fully booked, despite the higher-than-average fare. A ticket to Alma-Ata for the Tu-144 cost 68 roubles versus 48 roubles for a ticket to the same destination for a subsonic jet; by comparison, an average office clerk's salary in those days was 130 roubles. There were foreign nationals on virtually every single flight; makes you wonder if perhaps they bought the tickets specifically for the purpose of sampling the 'Concordski' and experiencing supersonic air travel at a fraction of the cost of 'the real McCoy'!

Questionnaires distributed among the passengers showed that most of the passengers were quite happy with the cabin, rating it as comfortable. Yet there was a deal of criticism as well; one Lady Whose Girth Defies Measurement complained that the seats were too narrow and uncomfortable, suggesting that wider seats be installed for portly passengers. Many female passengers were displeased with that fact that the meals served on the flight included a 33-cl bottle of dry wine; this allegedly created a queue for the loo and deprived them of the chance to powder their noses before arrival at Moscow! Still, every airline probably has a problem with such 'never-happy passengerettes who don't know a good thing when they see it', and such complaints should be ignored.

The last scheduled flight of a Tu-144 took place in May 1978. The official explanation as to why they were terminated is that Aleksey A. Tupolev was unsure that the type's operation was perfectly safe; also, Tu-144 operations required runways and ground equipment/services to be upgraded, and this was a costly and messy process, added to which, the type's operating costs were rather high. The unofficial explanation is that the anti-Tu-144 lobby had won. During the Soviet SST's all-too-brief service career Aeroflot crews had made 55 flights and carried 3,284 passengers.

What happened to the surviving Tu-144s afterwards? CCCP-77106 was donated to the Soviet Air Force Museum in Monino south of Moscow, CCCP-77107 and CCCP-77108 became ground instructional airframes at the Kazan' Aviation Institute (KAI) and the Kuibyshev Aviation Institute (KuAI) respectively; KuAI is now called the Samara State Aerospace University (SGAU). CCCP-77109 was stored at Voronezh-Pridacha. CCCP-77110 is on display at the Civil Air Fleet Museum in Ul'yanovsk. After sitting idle at Zhukovskiy for several years Tu-144D was sold to the Auto- und Technik Museum in Sinsheim, Germany, in 2000 and delivered there by barge (via the Moskva River, the Baltic Sea, the North Sea, the Rhine and the Neckar and then by road). CCCP-68001, CCCP-77105 and CCCP-77113 were scrapped; CCCP-77115 still sits at Zhukovskiy. CCCP-77114 became the

Another view of Tu-144D CCCP-77115 languishing at Zhukovskiy in company with one of the Tu-204 prototypes.

Tu-144LL testbed (see next chapter). The fate of the others is unknown.

Lessons Learned

Thus, the development and operation of the Tu-144 was not merely the creation of just another new airliner (or, God forbid, merely a 'can-do' exercise of expensive showmanship) – it truly marked a new lap in the development of aviation science and technology, yielding new structural materials and so on. The whole of the Soviet Union's scientific and technological potential associated with aircraft technology was brought into play and the following objectives were completed:

Knowledge was obtained and theoretical and practical methods were evolved of creating aerodynamic layouts offering a high lift/drag ratio at supersonic speeds. At Mach 2.2 the Tu-144 had a lift/drag ratio close to 8.0; by comparison, the production Tu-22 supersonic bomber had a lift/drag ratio no better than 4.4 at Mach 2.0, while the projected Tu-135 bomber was expected to achieve 6.4.

The development and refining of the Tu-144 was by far the largest and most complex programme the Soviet aircraft industry had tackled until then. The result was a world-class aircraft.

The Soviet engineers evolved methods of calculating stable and gradient temperatures of aircraft structures and methods of designing airframe structures able to withstand temperatures of 100-120°C (212-247°F). Typical airframe structures able to withstand kinetic heating cycles and the methods of their calculation were devised; manufacturing technologies and equipment for producing heat-resistant airframe structures (including those made of titanium) were developed. The foundations were laid for large-scale use of titanium in airframe structures.

Methods of creating heat-resistant structural materials, lubricants, sealants and so on were devised. As part of a joint effort with Western companies, the Tu-144LL testbed was created.

The ecological aspects of operating an SST (the emission of large amounts of exhaust gases at high altitude and the impact on the ozone layer) were explored. The effects of the SST's engine noise and sonic boom on people, animals and buildings were explored, as was the effect of solar radiation on the occupants of the aircraft during prolonged flight at high altitude.

A new air conditioning system ensuring passenger comfort during prolonged flight in kinetic heating conditions at up to 20,000 m (65,620 ft) was created.

New devices and systems enabling automatic flight control, accurate navigation during prolonged supersonic cruise and automatic landing were created.

The creation of the Tu-144 boosted the development of the Tupolev OKB's other heavy supersonic aircraft. Many of the Tu-144's aerodynamic and structural features, as well as its systems design philosophy, were used for the Tu-22M and Tu-160 multi-mode strategic bombers.

FÉDÉRATION AÉRONAUTIQUE INTERNATIONALE

Diplôme de Record

(U.R.S.S.)

NOUS SOUSSIGNÉS CERTIFIONS QUE Serguei Agapov, Pilote Chef de Bord

SUR Avion 101 Boris Veremci, Copilote

ont ÉTABLI LE 13 juillet 1983

LE RECORD SUIVANT du monde par catégorie: Vitesse en circuit fermé de 1000 km. avec charge de 30000 kg. : 2031,546 km/h. Podmoskovnoe

Classe C-1 Groupe III

Pour LE PRÉSIDENT, LE DIRECTEUR GÉNÉRAL DE LA F. A. I. LE PRÉSIDENT DE LA F. A. I.

The FAI diploma testifying to the world records set by Sergey Agapov and Boris Veremey in Tu-144D CCCP-77114 (referred to as the 'aircraft 101' to confuse Western intelligence agencies).

The Tu-144 in Detail

Since the original 1968 prototype (*izdeliye* 044) and the production-standard Tu-144/Tu-144D (*izdeliye* 004/004D) had major structural differences, they are described separately.

1968 Prototype Tu-144 in Detail

Type: Four-engined medium/long-haul supersonic airliner of tailless-delta layout. The airframe is of all-metal construction embodying the fail-safe design principle to enhance reliability and has a 30,000-hour designated service life over 15 years.

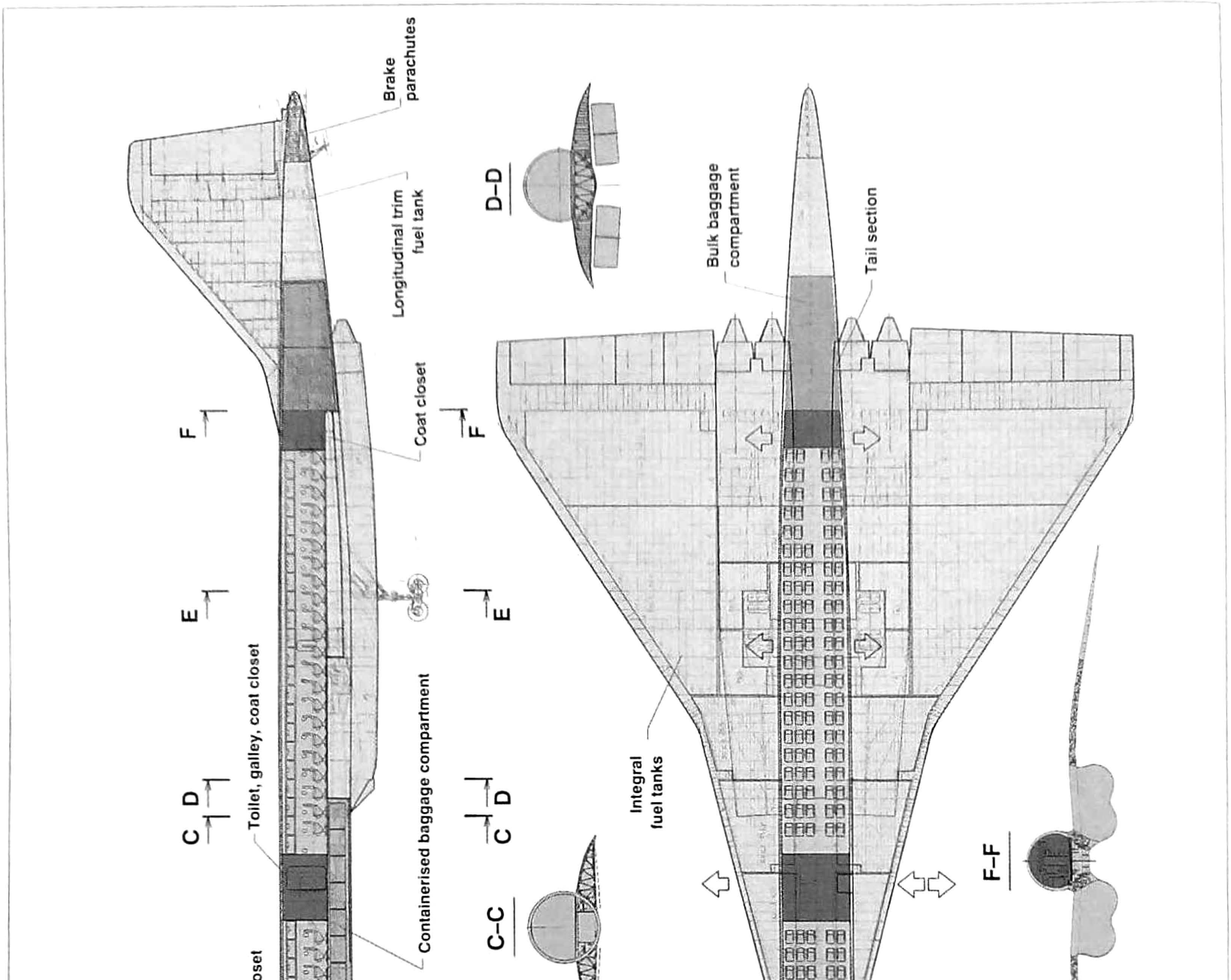
Fuselage: Semi-monocoque riveted stressed-skin structure with a high fineness ratio (about 20). The fuselage is largely manufactured of AK4-1 aluminium alloy, and flush riveting is used throughout. The fuselage cross-section changes from circular at the forward extremity to quasi-circular (formed by two arcs of different radii with the larger radius at the bottom, so that the underside is flattened) for most of the length and back to circular at the rear. The resulting cross-section enables comfortable five-abreast passenger accommodation while keeping the cross-section area to a minimum.

Structurally the fuselage is divided into three sections: the forward fuselage, the centre fuselage and the rear fuselage. The unpressurised *forward fuselage* is the sharply pointed movable nose visor which is drooped to improve the forward view on take-off and landing; it is hinged to the bottom of centre fuselage frame 15 and actuated by a duplicated electrically-driven screwjack, plus a back-up hydraulic drive forcing the visor down into an intermediate position. When the visor is raised for cruise flight, the upper/lower fuselage contours in the area are unbroken. The nose visor incorporates four dorsal glazing panels and one window on each side aft of them, providing a measure of forward view in cruise flight; it terminates in a conical glass-fibre radome tipped with a pitot.

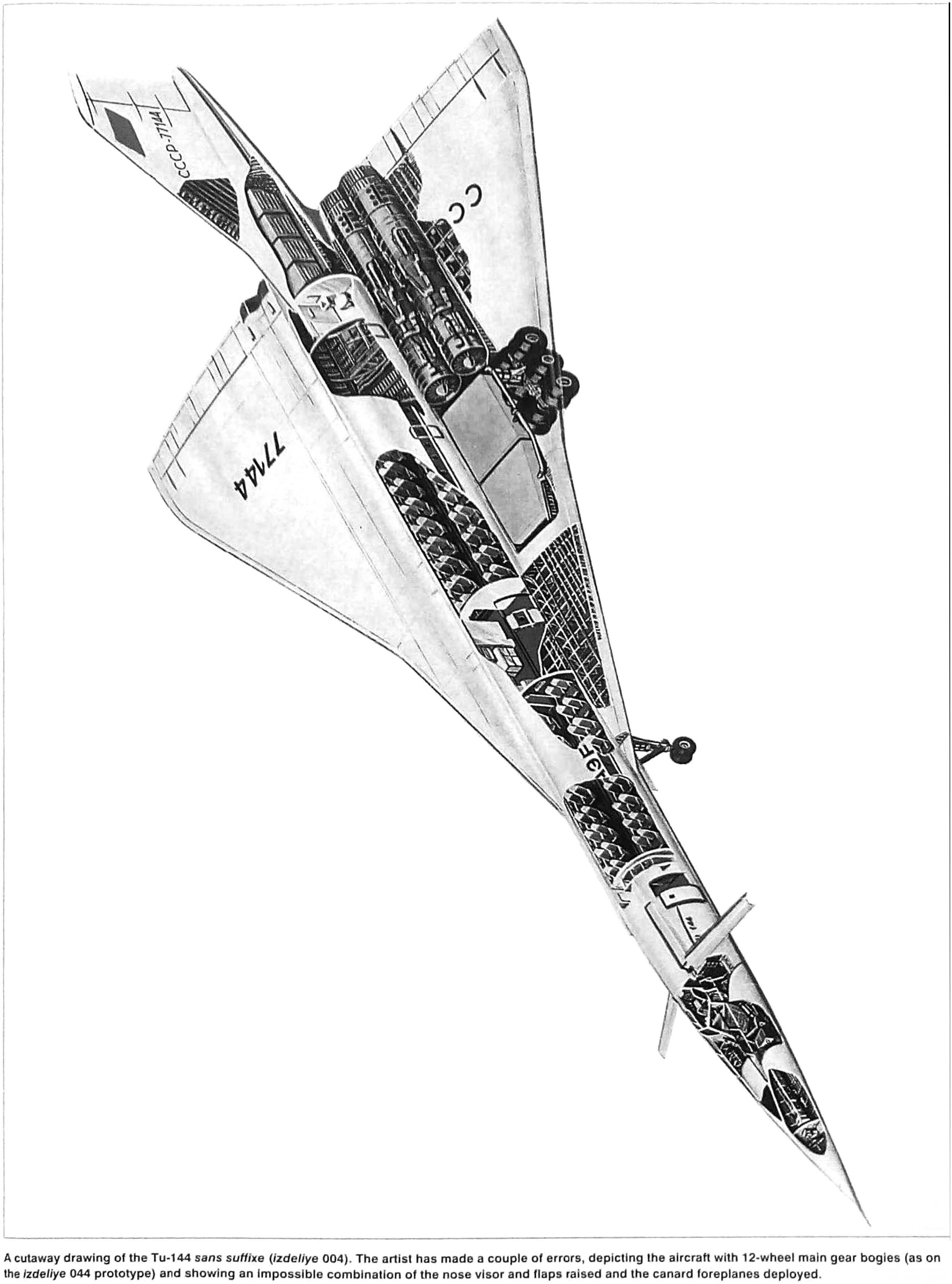
The *centre fuselage* (frames 8-108) is a pressure cabin terminating in the rear pressure dome; it includes the three-man flight-deck featuring a V-shaped windscreen (exposed when the nose visor is lowered) and two side windows on each side. The optically flat birdproof windscreen panes are made of

Above: This view illustrates the prototype's fuselage design with the dorsal windows in the drooping nose and the ejection hatches.

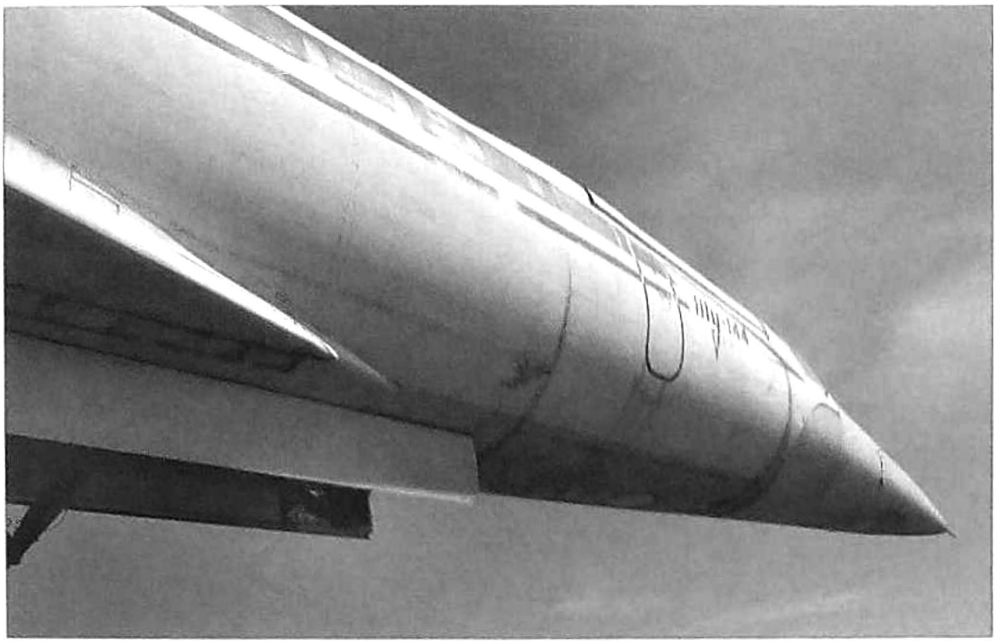
The centre fuselage and the wing/fuselage joint of a production-standard Tu-144 (*izdeliye* 004). The unusually small size of the windows is due to the strong heating at high mach numbers.



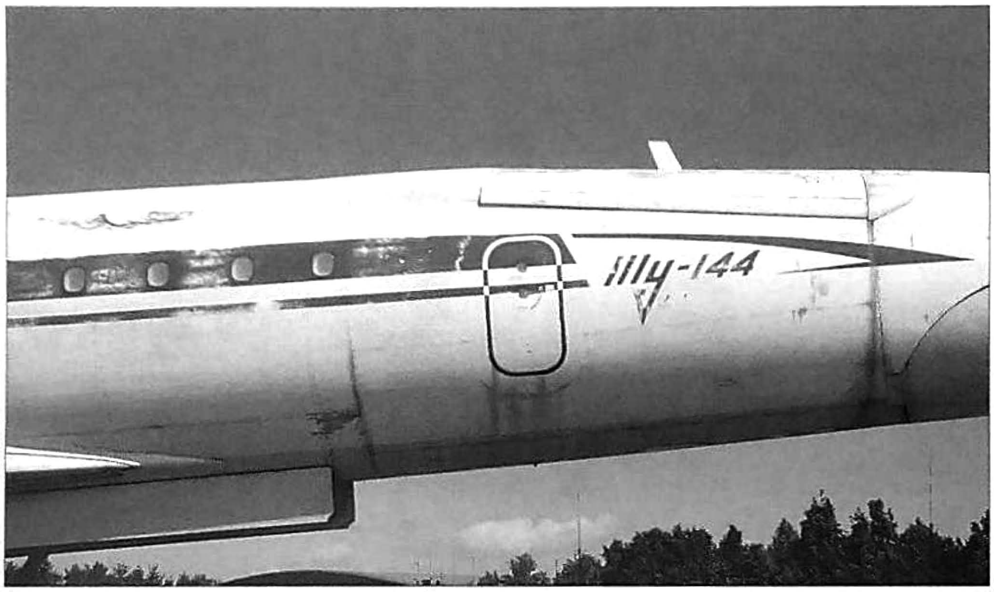
This cutaway drawing shows the internal layout of the Tu-144D.



A cutaway drawing of the Tu-144 *sans suffixe* (*izdeliye* 004). The artist has made a couple of errors, depicting the aircraft with 12-wheel main gear bogies (as on the *izdeliye* 044 prototype) and showing an impossible combination of the nose visor and flaps raised and the canard foreplanes deployed.



Above: The nose visor of a production Tu-144D (CCCP-77115) in fully raised position for cruise flight.



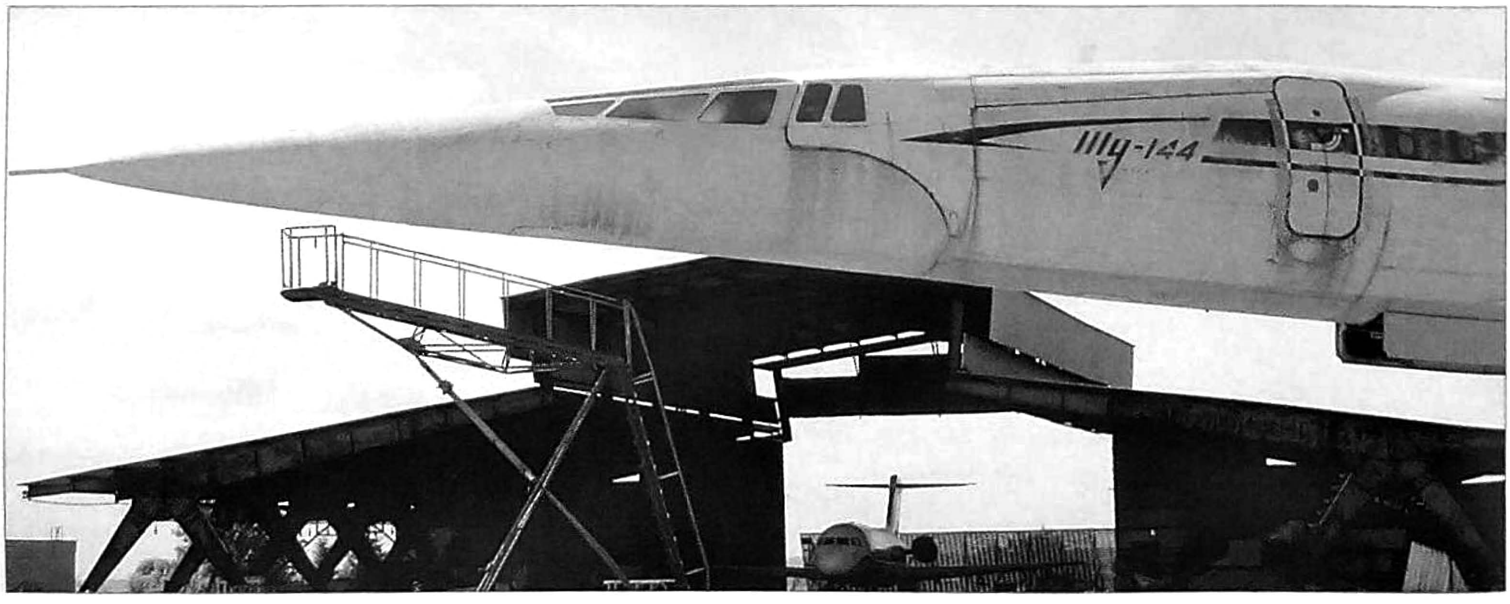
Above: The retracted canards (with the associated fairing which also carries a blade aerial) and the small No.1 service door with a reinforcing liner around it.

triplex glass 51 mm (2 in) thick. Located aft of the flightdeck are the No.1 avionics/equipment bay, the forward baggage compartment, the forward and aft passenger cabins, the toilets and the rear baggage compartment flanked by the two halves of the No.2 avionics/equipment bay. Along nearly half its length the fuselage is permanently attached to the wing centre section forming the cabins' pressure floor. A hefty longitudinal structure (the so-called centrebody) runs along the centreline below the wings, forming the lower load-bearing element of the fuselage and significantly increasing its rigidity.

The pressure cabin features a dynamic heat insulation system protecting it against the kinetic heating during supersonic cruise. The fuselage is lined from within by porous multi-layer panels, and cooling air from the cabin is forced between the layers.

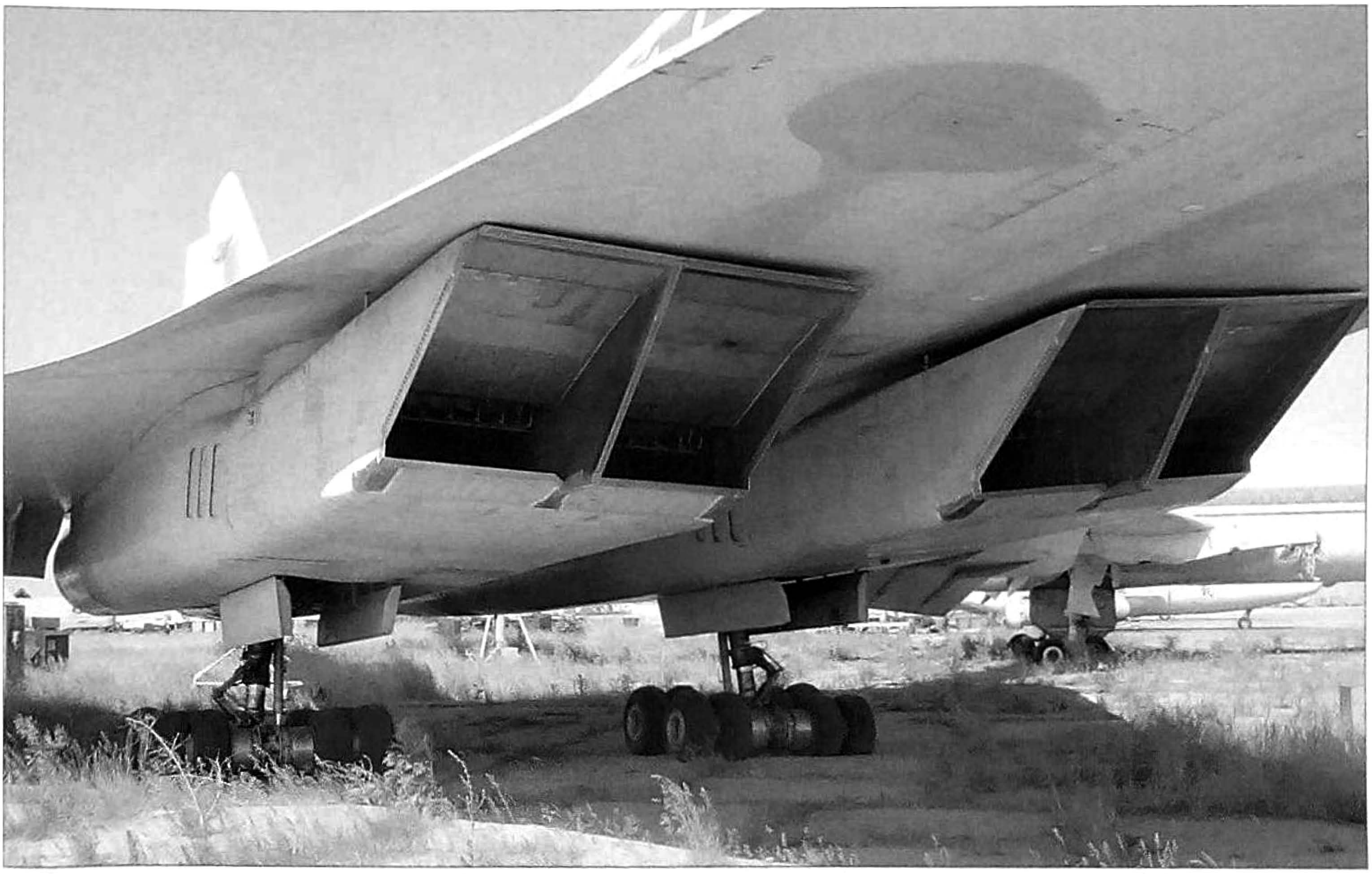
Two rectangular entry doors are located on the port side, swinging outward and forward on curved arms; two service doors of similar design intended for catering/baggage loading and emergency evacuation are located to starboard. The forward pair is positioned ahead of the wings and the rear pair above the wing LERXes. They are supplemented by two plug-type inward-opening rectangular overwing emergency exits on each side. The rear baggage compartment is accessed via an inward-opening ventral hatch aft of the engine nozzles.

The cabins feature oval windows with triple glazing set into large one-piece longitudinal panels forming part of the centre fuselage structure. The seat tracks and the design of the removable cabin bulkheads and galley units allows the cabins to be reconfigured for different seating arrangements. The interior trim of the cabins and entry vestibules is composed of easily detachable panels made of non-combustible synthetic materials.



Another view of the nose of Tu-144D CCCP-77115, showing the curved visor/forward fuselage joint line and the flightdeck glazing design. Note how much larger the port side entry door is. Tall work platforms are required for maintenance access.

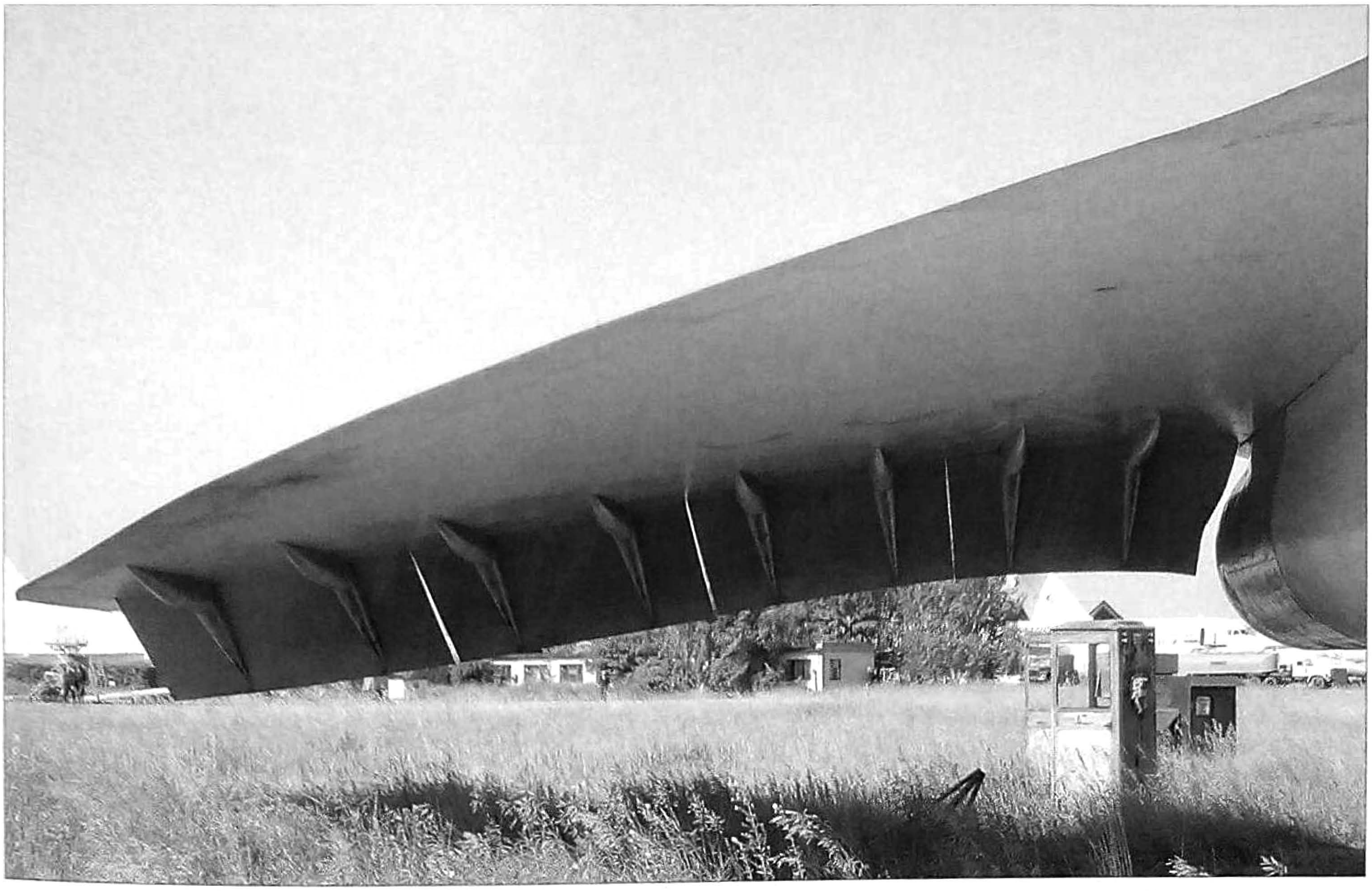
Above: Aeroflot flight attendants pose for a photo in the rear (main) cabin of the Tu-144 prototype (*izdeliye* 044) fitted out with a full complement of seats; note the overwing emergency exits located close together.



The wing centre section/LERXes and engine nacelles of a Tu-144D. This view illustrates the air intake design (note the boundary layer spill ducts) and the auxiliary blow-in doors on the sides of the nacelles.

Above: This view of the *izdeliye* 044 prototype shows the landing gear design, the position of the engine nozzles with respect to each other and the fuselage, and the curvature of the wing leading edge.

Another view of the wings and the front ends of the engine nacelles, showing how the LERXes mate with the main wings and blend into the fuselage. Note the design of the boundary layer spill ducts



Above: The wings of the production Tu-144 feature both spanwise camber (evident in this view) and chordwise camber. With no hydraulic power, the four-section elevons have 'bled' fully down. Note how the innermost section's inboard edge is shaped for better integration with the engine nacelle.

The spanwise curvature of the wing leading edge from the main wing/LERX junction looks quite curious from this angle. Note the fixed trailing-edge portion outboard of the elevons, the dorsal actuator fairings on the outermost elevon section and the unequal size of the emergency exits.

Top and above: The tail unit and rear fuselage of Tu-144D CCCP-77115, showing the asymmetrical placement of the rudder sections' actuator fairings, the titanium heat shield on the rear fuselage, the hinged brake parachute housing and the rear baggage compartment door on the starboard side.

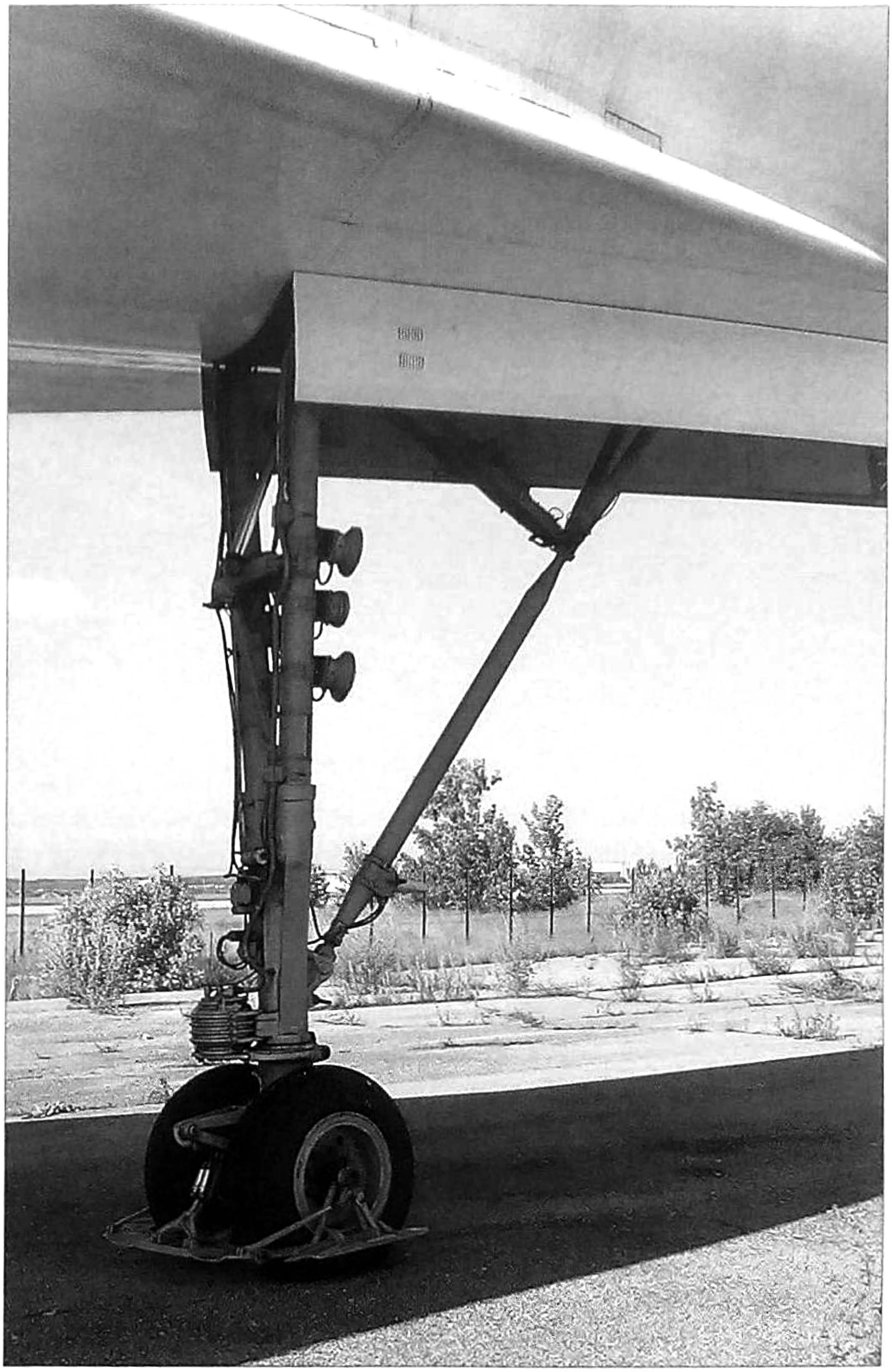
The unpressurised *rear fuselage* carries the tail unit. It accommodates the auxiliary power unit and the brake parachute container enclosed by an upward-hinged tailcone.

The actual *izdeliye* 044 prototype (CCCP-68001) has a different interior layout as compared to the project and incorporates structural changes associated with its flight test status. The crew is enlarged to four by introducing a test engineer; the flight engineer's workstation is moved aft to the forward cabin and located alongside the test engineer's workstation just ahead of fuselage frame 32. All four crewmembers sit on KT-1 ejection seats; hence two pairs of dorsal hatches with jettisonable covers are provided in the flightdeck roof and in the roof of the forward cabin a short way aft of the forward pair of doors, allowing the pilots and the test engineers to use their ejection seats in an emergency.

For safety reasons the crew section is isolated from the rest of the pressure cabin by an additional pressure dome at frame 32 to reduce the volume of the depressurised section in the event of decompression. Additionally, a flat bulkhead with a door is installed at frame 20, acting as an airflow damper in this situation.

The No.1 avionics/equipment bay located immediately aft of the pilots' seats is divided into port and starboard halves to make a passage to the flightdeck and houses the principal navigation, communication and control equipment. The port half houses the short-range radio navigation (SHORAN) system, the digital navigation computer and other navigation equipment, the horizontal situation indicator and Molniya radio set modules and the flight control system modules (the air data system and more). The starboard half houses more SHORAN modules, the Lotos radio, the identification friend-or-foe transponder, the weather/navigation radar set, the Raduga navigation receiver and the automatic fuel metering/usage equipment. This bay also houses oxygen bottles and electric transformers.

The bay between frames 20-28 is mainly occupied by test equipment. The rack on the starboard side houses data recorders for the navigation suite, automatic flight control system, electric system and aerodynamic measurements, while the one on the port side holds data recorders for the vibration monitoring suite. Further aft is a bay accommodating the flight engineer and test engineer with their control consoles (frames 28-32), followed by a remnant of the forward cabin in representative first-class configuration with nine seats three-abreast. The flight engineer's main bank of instruments is located at frame 28; there is also a side console and a port side bank of throttles which is linked to the main bank of throttles in the flightdeck and the autothrottle by push-pull rods.



The nose landing gear unit of a Tu-144D, showing the forward-mounted drag brace and breaker strut, the aft-mounted steering mechanism/shimmy damper and the hinged debris guard fitting around the wheels.

The second entry vestibule houses test equipment for the hydraulic and air conditioning systems, as well as some items of the aircraft's intended equipment fitted temporarily for lack of space (fire extinguisher bottles, circuit breaker panels and hydraulics modules).

The rear cabin (frames 50-85) is intended to accommodate 80 tourist-class passengers on 16 rows of seats five-abreast. At the initial flight test phase these were replaced by more test equipment mounted on the starboard side on detachable racks, the power cables for the equipment running along the starboard side of the cabin floor and, in part, along the overhead luggage racks. The test equipment caters for the fuel system and the strain gauges fitted to various parts of the airframe; the data link system is also installed in the rear cabin and there are provisions for installing cine cameras. The cabin also

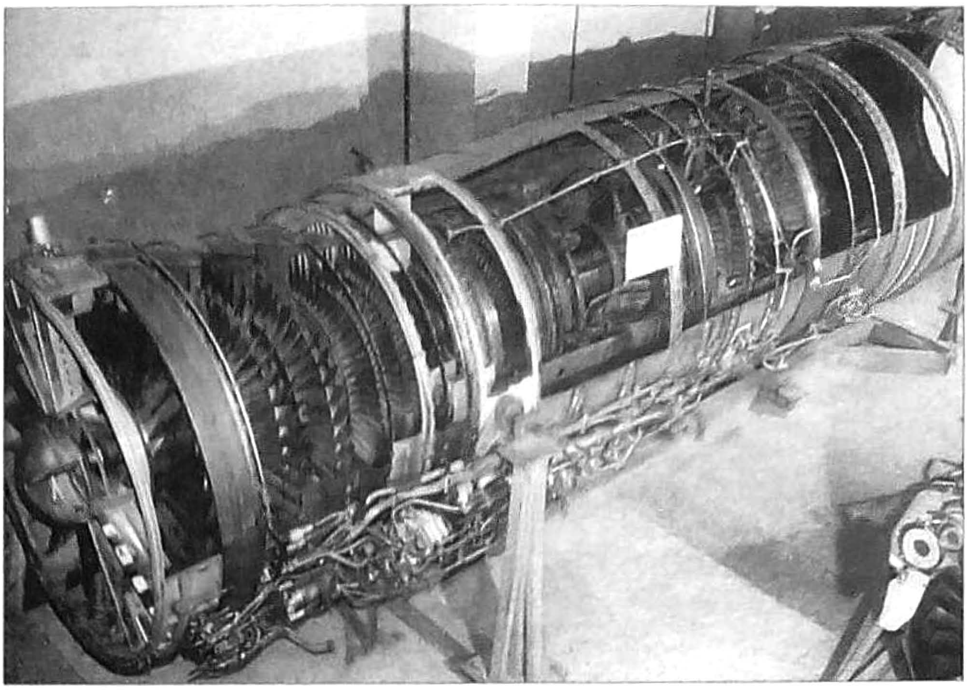
Above: The port main gear unit of a Tu-144D. The bogies are designed in such a way as to provide the widest possible wheel track; for this reason, and because of the mainwheels' small diameter, the brake assemblies are located outside the wheels.

Because the bogies tilt to align themselves with the oleos before retraction, the main gear oleos' torque links are located on the outside. Note the bogie tilting actuator on the inboard side.

accommodates some of the AFCS modules (the compact attitude and heading reference system, angle speed sensors and G-load sensors) attached to the seat tracks; a special well is provided under the cabin floor at frame 56 for the gyros of the Raduga system.

The front end of the No.2 avionics/equipment bay commencing at frame 87 houses the electrics distribution buses. This bay accommodates the modules of the automatic engine starting and monitoring system, the Midas navigation set, Mikron radio set (to port), the Biryuza radio altimeter and the DC batteries (to starboard), the water tank and the nitrogen bottles.

The rear baggage compartment houses more test equipment associated with the powerplant.



Above: A cutaway example of the Kuznetsov NK-144 engine used as a teaching aid.

Wings: Cantilever low-wing monoplane with low aspect ratio compound-delta wings featuring large leading-edge root extensions and an ogival leading edge; trailing edge has zero sweepback. The wings occupy two-thirds of the fuselage length. Gross wing area is 470 m² (5,053 sq ft), net wing area is 413 m² (4,440 sq ft).

The wings are stressed-skin structures made mostly of AK4-1 aluminium alloy. Structurally they are built in four pieces: the sharply swept forward section (a one-piece assembly combining the two LERXes), the centre section and two detachable outer wing panels; the forward and centre sections permanently attached to the fuselage serve as attachment points for the engine nacelle, the air intake trunks and the landing gear.

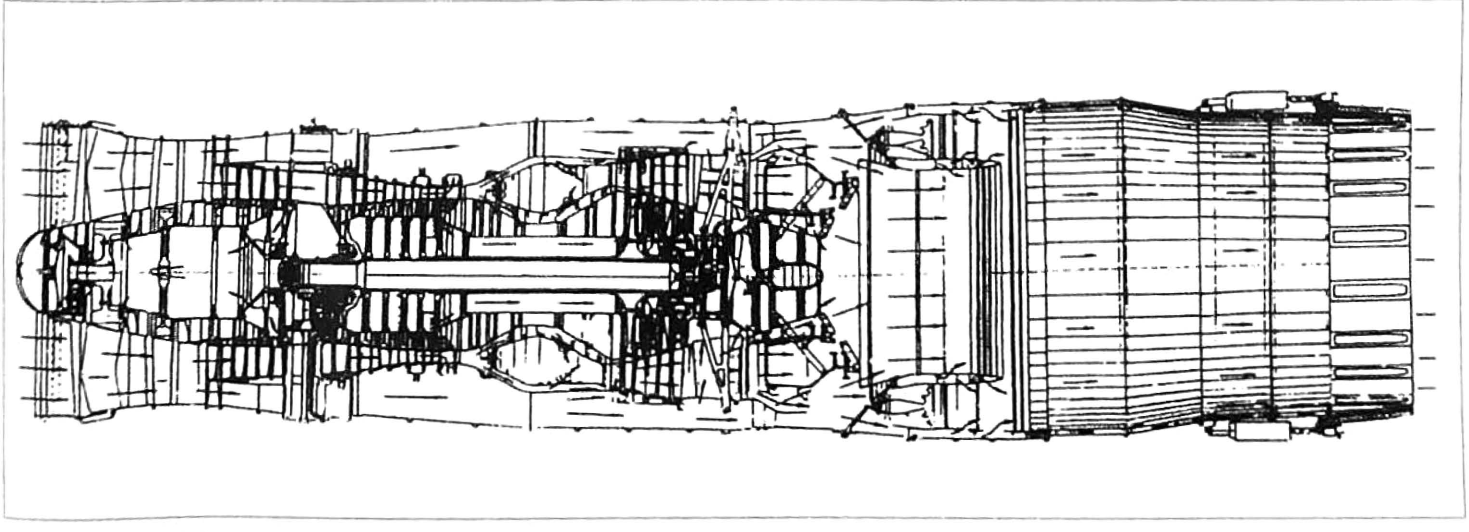
The *forward section* structure consists mainly of girder beams supporting the skin panels which are stiffened by spot-welded stringers. This part of the wings incorporates fuel tankage and the nosewheel fairing. The *centre section* is a multi-spar structure comprising milled skin panels with integral stiffeners supported by girder spars and girder ribs. It also incorporates integral fuel tanks, as well as the mainwheel wells and air conditioning system bays; the latter are accessible via removable panels.

The *outer wings* are joined to the centre section by flanges and are structurally similar to it; they incorporate integral tanks and house the elevon actuators. The outer wing trailing edge is almost entirely occupied by four-section elevons whose welded structure is made entirely of titanium alloy. Each section is suspended on two hinges and has twin ventral actuator fairings. The outermost portions of the trailing edge are fixed and carry multiple static discharge wicks.

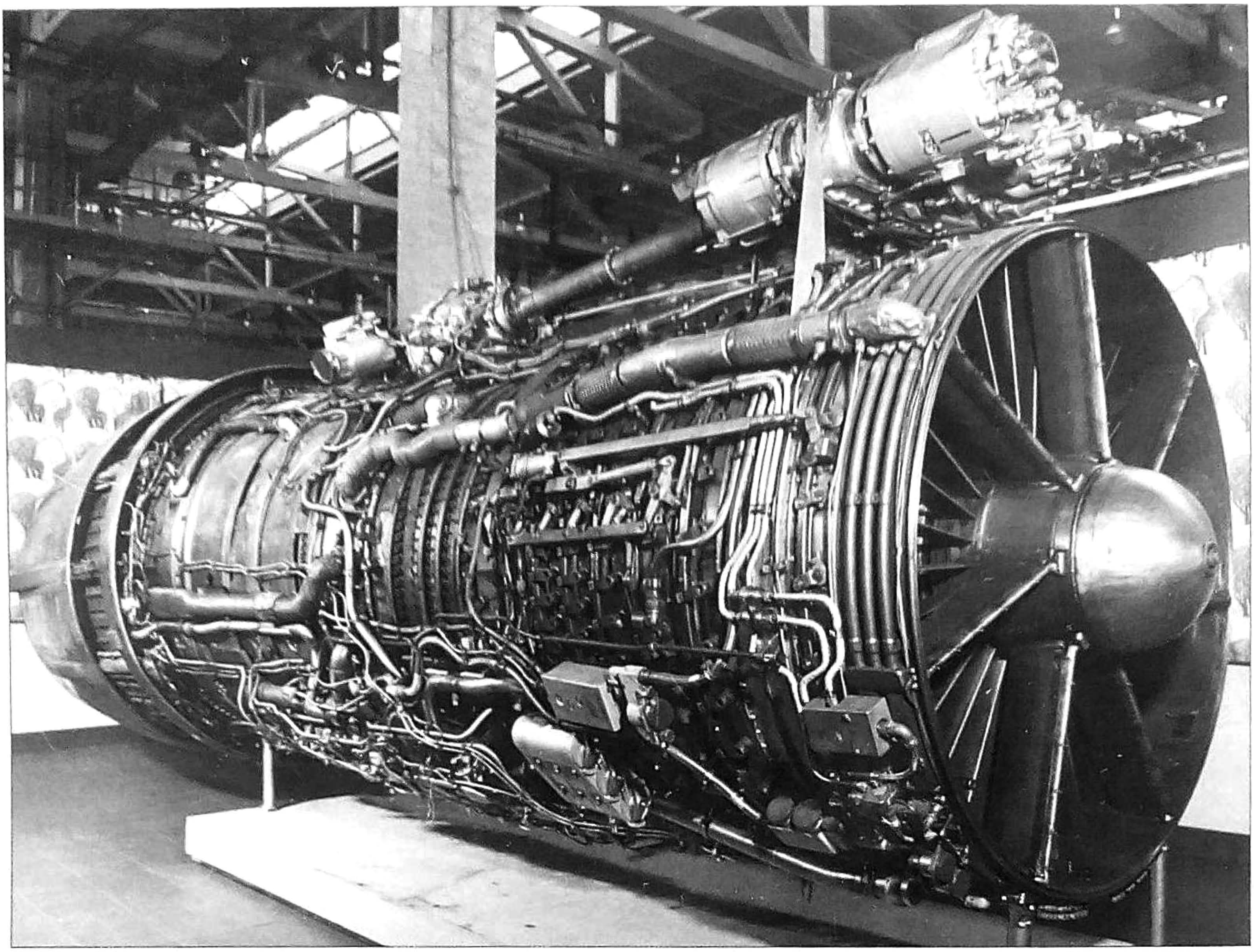
Tail Unit: Vertical tail only, comprising a large fin and an inset rudder. The fin is a one-piece subassembly and is similar in planform to the wings, with an ogival leading edge and no trailing-edge sweepback; the root fillet terminates ahead of the wing trailing edge. Structurally it is similar to the wing centre section, featuring a multi-spar stressed-skin structure with an integral fuel tank used for longitudinal trim in supersonic cruise. The two-section rudder is similar to the elevons, being made of titanium alloy; the twin actuator fairings are located to port on the lower half and to starboard on the upper half.

Landing Gear: Hydraulically retractable tricycle type, with pneumatic extension in an emergency; the landing gear is powered by either of two hydraulic systems. All three units have long-stroke oleo-pneumatic shock absorbers; these, together with longitudinal and transverse damping, ensure a smooth ride during taxying and take-off/landing.

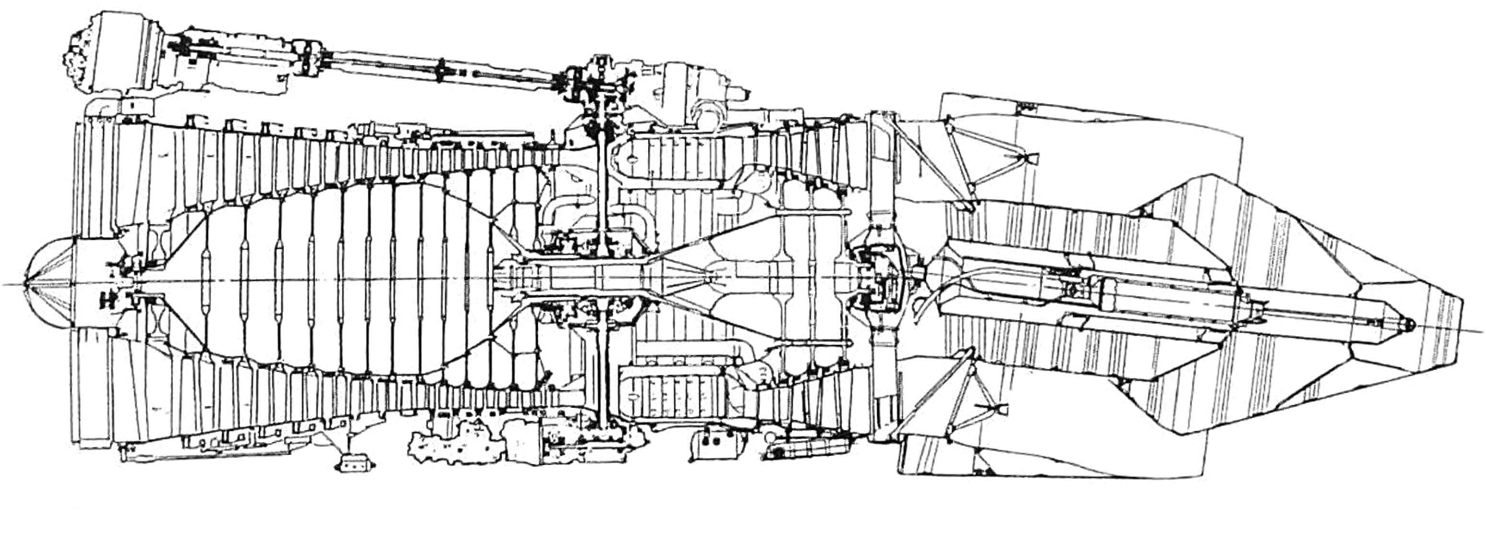
The aft-retracting nose unit located immediately ahead of the engine nacelle has a V-shaped main strut and a forward-mounted



A cutaway drawing of the NK-144



Above: A Kolesov RD36-51A engine, showing the accessory gearbox drive shaft and the raked struts connecting the fixed air intake spinner to the casing.

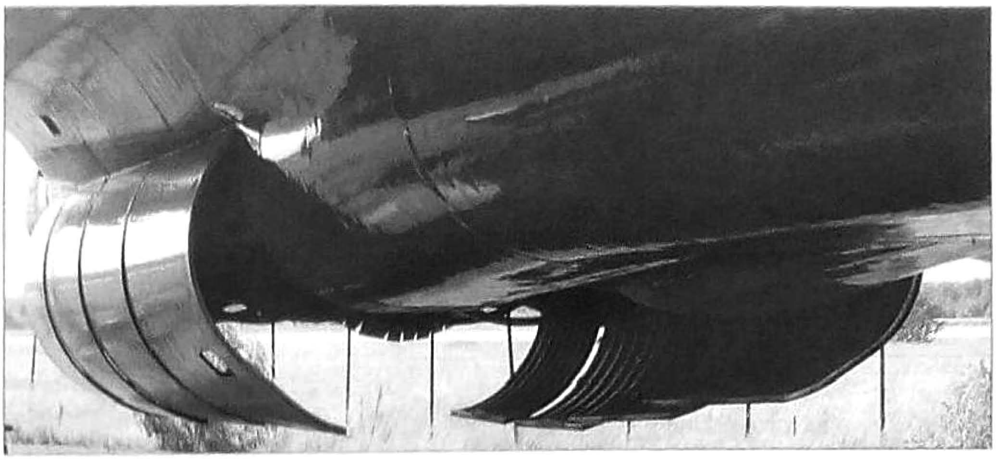


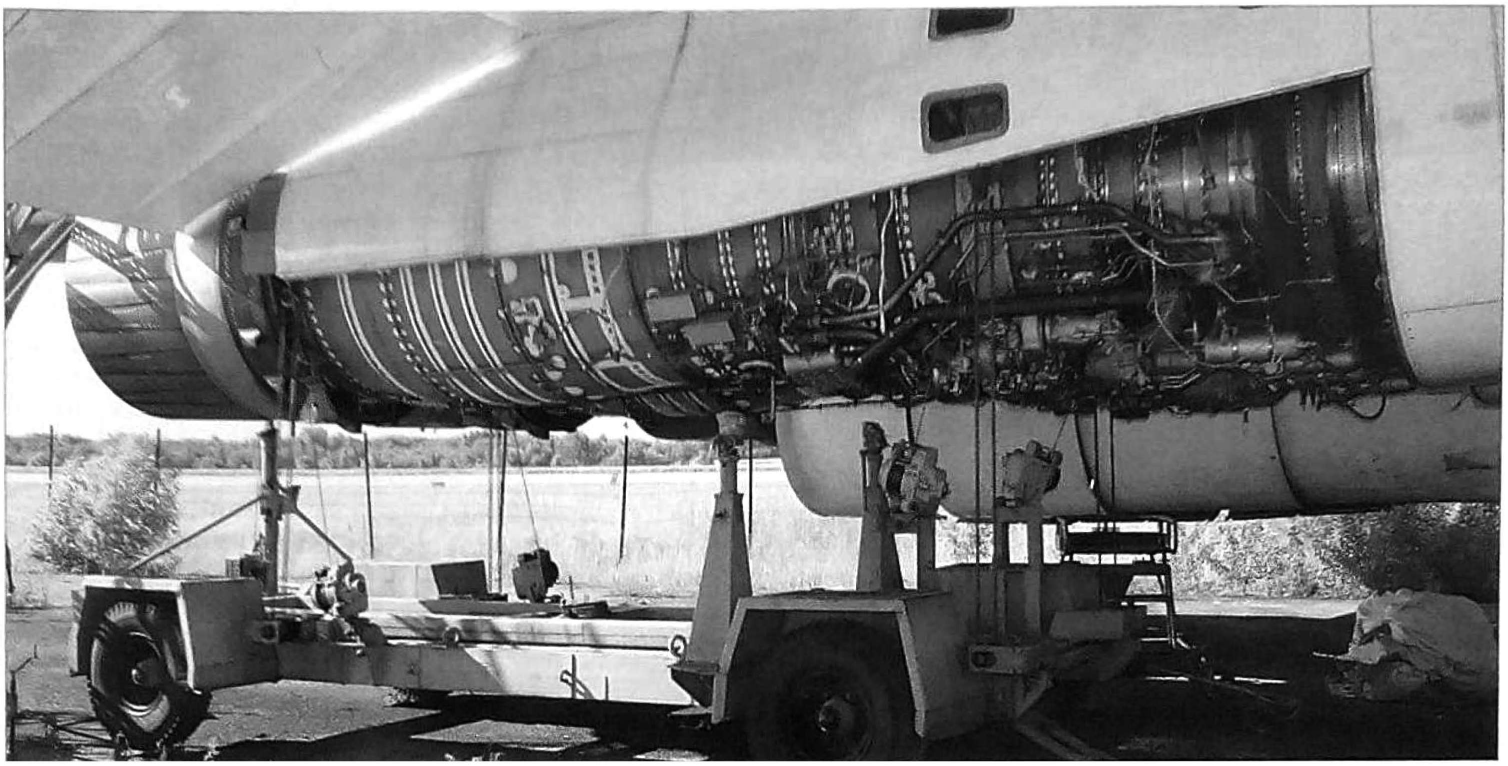
A cutaway drawing of the RD36-51A, showing how the ejector-type nozzle with the translating centrebody is angled downwards.

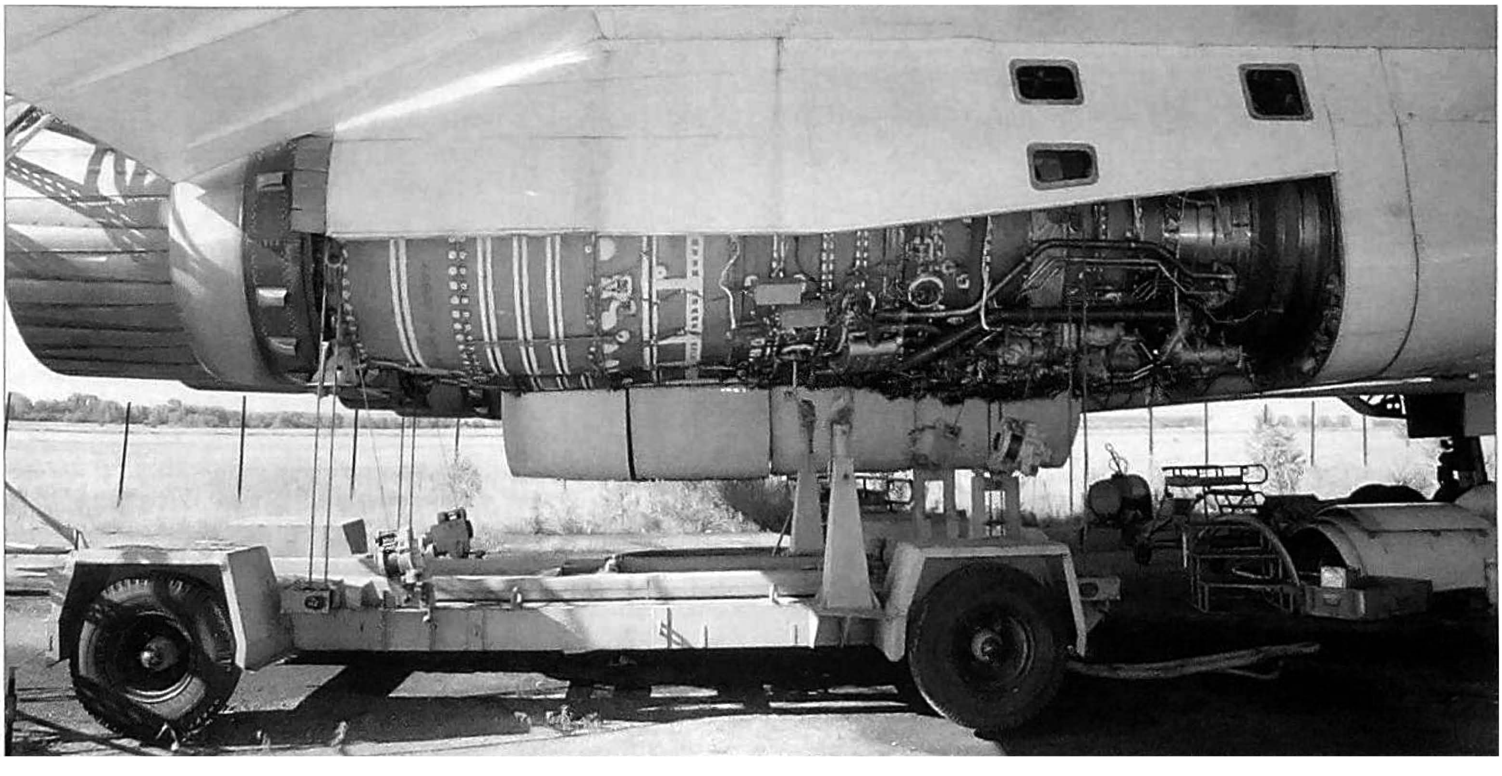
Right: This view shows how the large cowling panels of the production version hinged on the sides of the nacelles (four for each engine) provide good access to the engines.

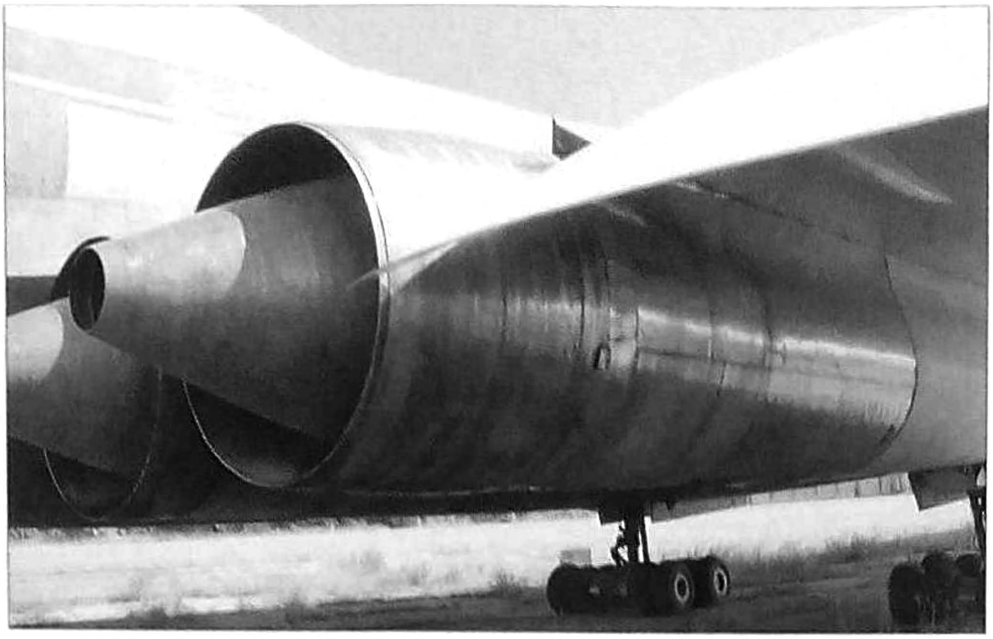
Below: The No.4 Kuznetsov NK-321 engine of the Tu-144LL research aircraft with the cowling removed prior to an engine change. The petals of the convergent-divergent nozzle are easily seen.

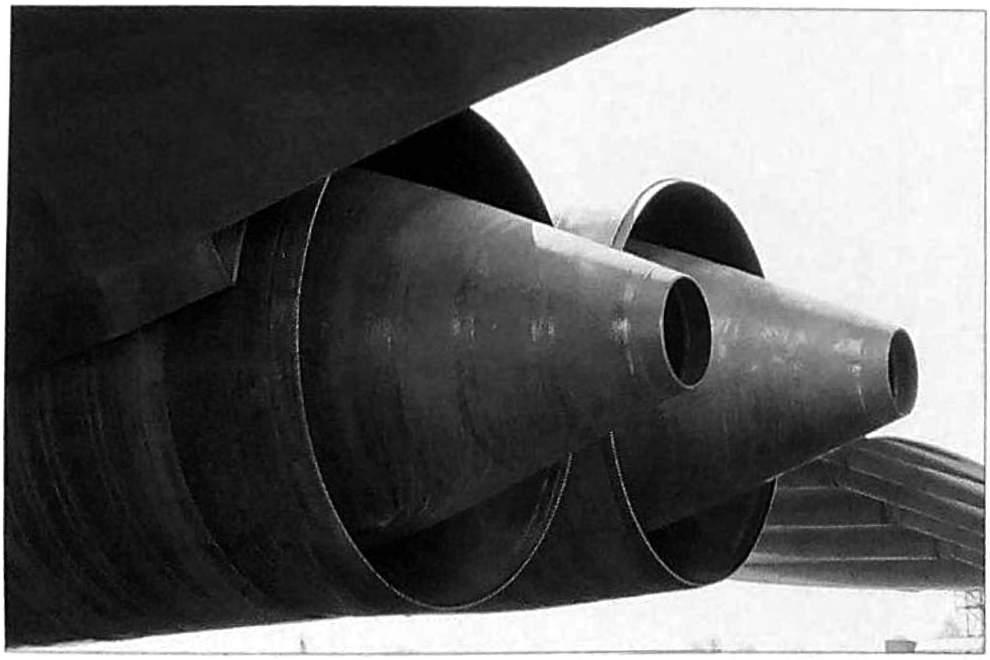
Bottom: A ground handling dolly is placed under the engine, ready for the engine to be winched down.











The RD36-51A has a very distinctive nozzle with a cropped translating centrebody adjusting the cross-section area. Note the air conditioning system outlet between the inner engine and the fuselage.

telescopic retraction strut, stowing in a triangular-section fairing located in the narrow space between the paired air intakes. It is fitted with twin 1,020 x 300 mm (40.15 x 11.81 in) non-braking wheels and equipped with a flat-plate mud/snow/slush guard. The nose unit features a steering mechanism/shimmy damper and is controlled by the rudder pedals. Steering angles for taxying are ±60°, ensuring adequate ground manoeuvrability.

The main units are located immediately outboard of the engine nacelle and retract forward into shallow bays in the wing centre section. Each unit has a long double-jointed ('knee-action') oleo strut, an aft-mounted telescopic retraction strut and a 12-wheel bogie fitted with 730 x 250 mm (28.74 x 9.84 in) wheels in three rows of four. The mainwheels feature disc brakes and built-in electric fans that keep the brakes from overheating.

The main gear bogies are attached to the oleo struts via universal joints allowing them to rock both fore-and-aft and sideways. During retraction they are rotated forward through 180° by separate hydraulic rams/rocking dampers to lie inverted in the wheel wells.

The nosewheel well is closed by two doors positioned well aft and by fairings attached to the nose gear strut. Each main unit has two large and suitably bulged main doors enclosing the bogie, two small clamshell doors in line with the gear fulcrum (enclosing the 'knee-action' strut) and a narrow fairing attached to the retraction strut. The large main doors open when the gear is in transit.

For emergencies or wet/icy runway operations the Tu-144 is equipped with twin brake parachutes housed in the tailcone, with a total area of 104 m² (1,118 sq ft).

Powerplant: Four Kuznetsov NK-144 axial-flow afterburning turbofans rated at 17,500 kgp (38,580 lbst) in full afterburner for take-off, with a minimum-afterburner cruise rating of 3,970 kgp (8,750 lbst) at 18,000 m (59,055 ft) and 2,350 km/h (1,460 mph) and a non-afterburning cruise rating of 3,000 kgp (6,610 lbst) at 11,000 m (36,090 ft) and 1,000 km/h (621 mph).

The NK-144 is a two-spool turbofan with a fixed-area subsonic air intake, a two-stage low-pressure (LP) compressor, a three-stage high-pressure (HP) compressor, an annular combustion chamber with multiple burners, a single-stage HP turbine, a two-stage LP turbine, an afterburner (common to the core and bypass flows) and a fixed-area nozzle. Construction is mostly of titanium castings and forgings. The air intake assembly has a fixed spinner and 18 radial struts. A ventral accessory gearbox is driven off the LP compressor shaft. The engine is started by an air turbine

starter, using compressed air supplied by the APU, ground supply or cross-feed from the other engines.

Bypass ratio 0.6. Overall engine pressure ratio at sea level 14.2. Turbine temperature 1,360°K. Specific fuel consumption 1.6 kg/kgp·hr (lb/lbst·hr) at take-off, 1.56 kg/kgp·hr in minimum-afterburner cruise and 0.965 kg/kgp·hr in non-afterburning cruise. Length overall 7.69 m (25 ft 2¾ in). Inlet diameter 1.355 m (4 ft 5$^{11}/_{32}$ in). Dry weight 3,540 kg (7,800 lb).

The engines are controlled from the pilots' central control pedestal and the flight engineer's station by means of push-pull rods and cable runs located under the floor. An autothrottle is provided.

All four engines are mounted side by side in a large common nacelle under the centre fuselage/wing centre section and separated by titanium firewalls. The nacelle's cross-section changes from rectangular at the front to modified oval at the rear. Despite the engines being grouped as closely as possible, the engine nacelle has a fairly large cross-section area of 12 m² (129 sq ft).

The engines breathe through two-dimensional supersonic air intakes featuring horizontal airflow control ramps; further downstream the inlet duct cross-section changes to circular. The front end of the nacelle is split (the air intakes are arranged in pairs with vertical splitters) to provide room for the nosewheel fairing; further aft the recess gradually narrows and becomes shallower until it vanishes.

To prevent boundary layer ingestion the intakes are set apart from the wing undersurface so that their upper lips act as boundary layer splitter plates. A V-shaped fairing spilling the boundary layer connects the intake lip of each pair to the wing undersurface; its shape is optimised for minimum drag. Part of the boundary layer is routed through special channels above the engines. Each inlet duct features a ventral bleed door which opens in cruise flight to spill excess air.

Access to each engine for maintenance or installation/removal is provided by three outward-hinged ventral cowling panels. The Nos 1 and 4 engines are provided with cascade-type thrust reversers which are part of the airframe, not the engine. The thrust reverser grids are inclined 15° outward to direct the jet blast away from the main gear wheels.

A Stoopino Machinery Design Bureau TA-6A auxiliary power unit is installed in the rear fuselage for self-contained engine starting, AC/DC ground power supply and air conditioning. The TA-6A has a three-stage axial compressor, a three-stage axial turbine and a GS-12TO DC generator/starter. Length overall 1,585 mm (5 ft 2$^{13}/_{32}$ in), width 620 mm (2 ft 0$^{13}/_{32}$ in), height 735 mm (2 ft 4$^{15}/_{16}$ in), dry weight (less generator) 245 kg (540 lb). The TA-6A can operate at ambient temperatures of −60°/+60°C (−76°/+140°F) and altitudes up to 3,000 m (9,840 ft); fuel consumption is 225 kg/hr (496 lb/hr). The air supply rate is 1.35 kg/sec (1.97 lb/sec), bleed air pressure 4.5 kg/cm² (64.28 psi).

Control System: Powered dual controls with irreversible hydraulic actuators in all three control channels; the actuators deliver a force of 13,000 kgf (28,660 lbf). The actuators are powered by four separate hydraulic systems for maximum reliability and are connected to the control columns and rudder pedals by conventional mechanical linkages (push-pull rods and bellcranks) passing under the floor. The control circuits feature spring-loaded artificial-feel units. An autopilot linked to the compass system and the navigation suite is fitted.

Pitch and roll control is provided by elevons on the outer wings; they are divided into four sections for greater reliability and ease of handling at different speeds. Directional control is provided by a two-section rudder.

The controls and instruments in the flightdeck are grouped according to their operational use. The instrument panels located in front of the pilots hold the primary flight instruments, the radar display, the horizon and direction indicator and the engine monitoring instruments. The central control pedestal carries the bank of throttles (with reverse thrust control levers for the outer engines), the wheel brake control handle, the nose visor control handle and the control panels for the autothrottle, the AFCS and the digital navigation computer. The side consoles accommodate the switches associated with the communications suite and some other systems. The overhead circuit breaker panel features the controls of the navigation suite, the fire suppression system and other systems. The control wheels incorporate switches and indicator lights for activating certain flight modes.

Fuel System: The wings and the fin torsion box house a total of 17 integral fuel tanks. Total fuel capacity is 102,000 litres (22,440 Imp gal). The fuel transfer and usage sequence is observed automatically to maintain the required CG position throughout the flight. Nitrogenated fuel is used to ensure thermal stability and reduce the fire hazard in kinetic heating conditions. The kerosene is processed at ground facilities by blowing nitrogen through it to substitute the dissolved oxygen, and during the climb and in cruise flight the kerosene gives off nitrogen which fills the empty space in the fuel tanks.

Hydraulics: Four separate hydraulic systems, each with its own reservoir, operating the control surface actuators, the landing gear, nosewheel steering mechanism, wheel brakes, nose visor emergency actuator and fuel transfer pumps. Hydraulic power is provided by eight NP-85 plunger-type pumps (two on each engine), each system including two pumps driven by different engines, and by a back-up pump driven by an air turbine. With two or three engines inoperative, available hydraulic power is reduced and limits are imposed on the flight envelope. If all four engines fail, hydraulic power is still available due to the engines windmilling; at 3,000 m (9,840 ft) and below the APU can be started up to power the air turbine pump.

The hydraulic lines incorporate tension compensators to allow for the expansion and shrinkage of the airframe due to kinetic heating and subsequent cooling. Hoses are used to connect the hydraulic lines to hydraulic equipment powered by several systems. Total hydraulic system capacity is 400 litres (88 Imp gal). Nominal pressure 210 kg/cm² (3,000 psi).

Electrics: The primary electric system uses 208/120 V/400 Hz three-phase stable-frequency AC supplied by four 60-kVA engine-driven generators. The oil-cooled generators and their hydromechanical constant-speed drives are built as integral units with a common oil system; the CSDs ensure a stable generator speed (and thus AC frequency) at accessory gearbox output shaft speeds between 320 and 6,500 rpm. The APU features a 40-kVA AC generator and a 12-kW DC generator. Backup 24 V DC power is provided by two lead-acid batteries housed in the No.2 avionics/equipment bay.

The distribution buses are located in the No.2 avionics/equipment bay, with circuit breaker panels amidships (in the second entry vestibule) and in the crew section and with transformers in the No.1 avionics/equipment bay. The main wiring bundles run along the cabin roof. Ground power receptacles are provided on the underside of the engine nacelle's rear portion, offset to port.

Nitrogen System: The nitrogen system jettisons the roof hatches above the crew's ejection seats, deploys and jettisons the brake parachutes, controls the valves linking the fuel tanks and pressurises the hydraulic tanks. It is charged with nitrogen at 150 kg/cm² (2,142 psi); the nitrogen bottles are located in the No.2 avionics/equipment bay.

Fire Suppression System: Fire extinguisher bottles which are charged with 114V$_2$ grade chlorofluorocarbon are provided for fighting fires in the engine bays and in the APU bay. In the event of an engine fire the flow of cooling air through the bay of the affected engine is shut off to prevent flame propagation.

Air Conditioning & Pressurisation System: The entire fuselage between frames 8 and 108 is pressurised by engine bleed air. The air conditioning system (temporarily located at the rear of the forward cabin behind the additional pressure dome during the initial flight tests) ensures an agreeable microclimate for the occupants throughout the flight envelope.

Avionics and equipment: The Tu-144 is fully equipped for poor-weather day/night operation, including automatic flight assisted by an autopilot. The *navigation and piloting equipment* includes a compass system enabling automatic route following, an instrument landing system (ILS) including localiser, glideslope beacon and marker beacon receivers, a short-range radio navigation system, a *Biryuza* (Turquoise) radio altimeter, a *Groza* (Thunderstorm) weather radar in a nose radome and other equipment.

The *communications equipment* includes a *Mikron* (Micron) communications/command link HF radio (located in the No.2 avionics/equipment bay) and a Lotos radio for short-range air/air and air/ground communications, plus an intercom. The *IFF system* comprises an *izdeliye* 020M ATC/IFF transponder. *Data recording equipment* includes an MSRP-12-96 primary flight data recorder on the port wall of the rear baggage compartment, plus miscellaneous data recorders associate with the test equipment suite (see Fuselage).

The flightdeck of a production Tu-144. The flight engineer's workstation with its second bank of throttles and engine instruments is in the foreground; curiously, each of the four throttle levers is set at a different angle.

Production Tu-144/Tu-144D in Detail

Type: Four-engined medium/long-haul supersonic airliner of tailless-delta layout designed for operation on both domestic and international services. The aircraft was designed with due regard to international requirements applying to contemporary airliners as regards operational reliability, flight safety and economic efficiency. The Tu-144's aerodynamic layout ensures a lift/drag ratio of 8.0 at a cruising speed of Mach 2.2.

The airframe is of all-metal construction embodying the fail-safe design principle. In common with the *izdeliye* 044 prototype the production-standard *izdeliye* 004/004D makes large-scale use of panels with integral lengthwise and transverse stiffeners, chemically milled skin panels and flexible fittings reducing the stress on the airframe caused by cyclic expansion/contraction due to kinetic heating.

Fuselage: Semi-monocoque riveted stressed-skin structure with a high fineness ratio; the skin is supported by extruded frames and stringers. The fuselage has a basically circular cross-section (except for the area aft of the flightdeck where the retractable foreplanes are located), with a maximum diameter of 3.5 m (11 ft 5¾ in), and its contours and dimensions differ considerably from the original prototype's.

Structurally the fuselage is divided into four sections: the movable nose visor, the forward fuselage, the centre fuselage and the rear fuselage. The unpressurised *nose visor* hinged to the bottom of the forward fuselage incorporates three narrow windows on each side providing a measure of forward view in cruise flight; it terminates in a conical glass-fibre radome tipped with a pitot. The visor is depressed 11° for take-off and 17° for landing. It is actuated by a duplicated electrically-driven screwjack, with hydropneumatic lowering in an emergency; the controls for normal and emergency actuation are located on the central control pedestal and the flight engineer's instrument panel respectively.

The *forward fuselage* (from the forward pressure dome up to frame 19) accommodates the three-man flightdeck, the forward entry vestibule and equipment racks. The flightdeck glazing comprises a V-shaped windscreen (exposed when the nose visor is lowered) and two side windows on each side; the rearmost pair of side windows are sliding direct vision windows. On pre-production examples used in the flight test programme a rectangular flightdeck escape door with external hinges was located on the port side just aft of the windows (it was eliminated on later machines); this forward-opening hydraulically-actuated door acted as a slipstream deflector, allowing the crew to bail out in an emergency.

A rectangular entry door is located on the port side, with a smaller service door opposite. These are of similar design to the doors of *izdeliye* 044 but swing outward and aft, not forward. A dorsal fairing and two recesses immediately aft of the flightdeck accommodate the retractable foreplanes (see Wings).

The *centre fuselage* (frames 19-110) terminating in the rear pressure dome forms a common pressure cabin together with the forward fuselage; it has a cylindrical shape but curves slightly upward at the rear end to lessen the drag at the junction with the cambered wings. Most of it is occupied by the passenger cabins and the second entry vestibule featuring a second pair of entry/service doors. Two pairs of plug-type rectangular overwing emergency exits are located halfway down the length of the rear cabin and at its rear end. The cabins have 43 oval windows with triple glazing made of Plexiglas on each side.

The nosewheel well is located between frames 20-31. Immediately aft of it is the forward baggage compartment (frames 31-66) with a capacity of 9.7 m³ (342.5 cu ft) located under the cabin floor; it is designed for carrying containerised baggage and accessed via a ventral door between frames 34-36. Further aft is the No.1 avionics/equipment bay (frames 66-70) accessible from inside the cabin via removable panels in the cabin floor. The rear baggage compartment with a capacity of 11.4 m³ (402.5 cu ft) located between frames 96-110 is intended for bulk baggage; it is flanked by the two halves of the No.2 avionics/equipment bay (frames 96-98) and likewise has a ventral loading hatch.

Along most of its length the centre fuselage is mated to the wing centre section forming the cabins' pressure floor. Again, a large load-bearing subassembly (the so-called centrebody) made up of monolithic milled panels with integral stiffeners encloses the wing/fuselage joint from below. Its forward portion forms part of the integral fuel tank structure, while the unpressurised rear portion houses hydraulic equipment and control system components; the rear wing/fuselage fairings flanking the centrebody accommodate the air conditioning system.

The unpressurised *rear fuselage* (frames 110-128) carries the tail unit. It accommodates an integral fuel tank used for longitudinal trim, a retractable tail bumper and the brake parachute container enclosed by an upward-hinged tailcone incorporating navigation system antennas.

Wings: Cantilever low-wing monoplane with low aspect ratio compound-delta wings featuring large LERXes and a cranked leading edge (leading-edge sweep 76° inboard of the kink and 57° outboard); the trailing edge has zero sweepback. Aspect ratio 1.635, taper 7.09; the wings feature spanwise and chordwise camber. The wing planform minimises the shift of the wings' aerodynamic centre as the aircraft slips through the sound barrier. The shape/camber of the wing centre section is optimised for ensuring good longitudinal trim and maximising the lift/drag ratio in supersonic cruise mode. The wing shape was chosen in such a way as to provide the optimum (required) wing deformation of the wing centre section at Mach 2.2 with due regard to the wing flexure.

The basic delta portion of the wings (less LERXes) utilises the TsAGI P-109S high-speed airfoil with a thickness/chord ratio of 2.4%. Inboard of the leading-edge kink (that is, on the LERXes) the airfoil gradually changes to TsAGI P-53S with a thickness/chord ratio of 2.8% at the roots. By virtue of the low thickness/chord ratio, the sharp leading edge on the outer wings and the relatively blunt leading edge of the LERXes this set of airfoils offers minimum drag in both subsonic and supersonic modes. The rational spanwise distribution of the thickness/chord ratios also accounts for the Tu-144's low wave drag.

The wings are stressed-skin multi-spar structures. Structurally they are built in seven pieces: the nose sections (port and starboard), the forward sections (port and starboard), the centre section (which is the main load-bearing component) and two detachable outer wing panels.

The *nose sections* (attached to the fuselage between frames 23-47) and the *forward sections* (frames 47-66) are joined together to form single airframe subassemblies before they are mated to the fuselage and the wing centre section. The portions between frames 31-66 are 'wet', housing two integral tanks separated by a bulkhead at frame 47.

The *centre section* is attached to the fuselage between frames 66-96, forming the pressure floor of the cabin, and extends as far as ribs 11L/11R. It carries the engine nacelles and houses six fuel tanks, including four service tanks from which the engines are fed. The structure includes eleven spars and 23 ribs (No.1 is the centreline rib).

The *outer wings* (ribs 11-36 on each side) are joined to the centre section by flanges. Each outer wing section has eleven spars, ribs (mostly girder-type), ten detachable upper skin panels and ten lower skin panels. The outer wings incorporate integral tanks. The spar webs and rib webs (on the 'solid' ribs) are corrugated to compensate for the cyclic expansion/contraction. The torsion boxes carry the trailing-edge sections, detachable leading edge sections and tip fairings. To save weight, the spars and ribs are manufactured with a variable cross-section, using computer-controlled milling machines.

The outer wing trailing edge is entirely (or almost entirely) occupied by four-section elevons whose welded structure is made entirely of titanium alloy. Each section is suspended on two hinges and has twin ventral actuator fairings (the outermost sections have dorsal fairings as well). The outermost portions of the trailing edge are fixed on late-production Tu-144s *sans suffixe* and Tu-144Ds.

The Tu-144's aerodynamic layout ensures good field performance and take-off/landing behaviour. The vortices generated by the LERXes energise the airflow over the wings, giving a 15% increase in lift. At extremely low altitude the wing lift increases by 50% thanks to the air cushion effect created by the large cambered wings. Lowering the elevons 10° in flap mode for take-off and landing provides a further 40% increase in lift but creates a pitch-down force. To neutralise the latter, high aspect ratio shoulder-mounted canard foreplanes of relatively small area are mounted aft of the flightdeck, retracting aft into a special fairing and recesses in the fuselage when not in use.

When deployed, the canards have 15° anhedral. For maximum efficiency they are equipped with double-slotted leading-edge slats and double-slotted trailing-edge flaps. The foreplane pivots are located between fuselage frames 6-7. The foreplanes are actuated by an IUS-3PTV electric drive mechanism via reduction gear and VP-7 screwjacks (*vintovoy podyomnik*), the high-lift devices deploying automatically by means of mechanical linkages as the canards swing into position.

Tail Unit: Vertical tail only, comprising a large fin and an inset rudder. The fin is a one-piece subassembly built integrally with the rear fuselage and has a trapezoidal planform with a kinked leading edge and a large root fillet terminating ahead of the wing trailing edge. Leading-edge sweep 50°, no trailing-edge sweep, thickness/chord ratio 3.0-3.5%.

The fin structure comprises a torsion box with 12 spars (Nos 4-12 are integrated into the rear fuselage structure), regular and reinforced ribs, a leading-edge false spar, milled and extruded skin panels, leading-edge and tip fairings (the tip fairing houses a radio antenna), a trailing-edge section and a root fillet. The two-section rudder is similar to the elevons, being made of titanium alloy; the twin actuator fairings are located to port on the lower half and to starboard on the upper half.

Landing Gear: Hydraulically retractable tricycle type; all three units retract forward. All units have two-chamber oleo-pneumatic shock absorbers and scissor links.

The semi-levered-suspension nose unit attached to fuselage frame 31 has an inverted-A shaped strut carrying the shock absorber and a forward-mounted breaker strut with a locking mechanism. It is fitted with twin 960 x 300 mm (37.79 x 11.81 in) non-braking wheels rotating together with the axle and a flat-plate mud/snow/slush guard. The nose unit features an aft-mounted steering mechanism/shimmy damper and is remote-controlled via the rudder pedals.

The main units are located underneath the engine nacelles, retracting into narrow wheel wells located between the inlet ducts of each pair of engines. Each unit has a short oleo strut, two breaker struts and a wide-track eight-wheel bogie fitted with 950 x 400 mm (37.40 x 15.74 in) wheels in two rows of four, with tubeless tyres. The mainwheels are equipped with multi-disc brakes and built-in electric fans that keep the brakes from overheating. Auto-brake and anti-skid units are provided; the anti-skid unit monitors each wheel separately and its rpm counters are integrated with the brake cooling fans.

The main gear bogies are attached to the oleo struts via universal joints allowing them to rock both fore-and-aft and sideways. During retraction they are tilted by separate hydraulic rams/rocking dampers so that the axles are disposed in line with the outward-canted oleo struts (with the inboard ends uppermost) before the struts swing forward (that is, the wheels remain vertical but at 90° to the direction of flight).

The nosewheel well is closed by two pairs of doors. Each main unit has two large main doors and a small rear segment linked to the oleo strut. All doors remain open when the gear is down.

A retractable tail bumper is built into the rear fuselage to protect it in the event of over-rotation or a tailstrike. For emergencies or wet/icy runway operations the Tu-144 is equipped with twin brake parachutes housed in the tailcone.

Powerplant: The Tu-144 *sans suffixe* is powered by four Kuznetsov NK-144A afterburning turbofans – an uprated version of the NK-144 (see description above) delivering 20,000 kgp (49,020 lbst) in full afterburner for take-off, 5,000 kgp (11,020 lbst) in minimum-afterburner cruise at 18,000 m (59,055 ft) and 2,350 km/h (1,460 mph) and 3,000 kgp (6,610 lbst) in non-afterburning cruise at 11,000 m (36,090 ft) and 1,000 km/h (621 mph).

Bypass ratio 0.6; overall EPR at sea level 14.75; mass flow at take-off power 236 kg/sec (520 lb/sec). Turbine temperature 1,390°K. SFC 1.65 kg/kgp·hr at take-off, 1.81 kg/kgp·hr in minimum-afterburner cruise and 0.92 kg/kgp·hr in non-afterburning cruise. The dimensions and weight are identical to those of the NK-144 *sans suffixe*.

Engine operation is monitored by means of ITE-2T tachometers, EMI-3FTIS multi-function engine indicators, UV-33 throttle lever position indicators, UP-21 nozzle position indicators, the IA-7A-950 exhaust gas temperature measurement kit with sensors located ahead of the LP turbine, and the IV-144 vibration monitoring kit. The engines are provided with a surge prevention system and an SG-9 afterburner control/indication system.

The Tu-144D is powered by four Kolesov RD36-51A axial-flow non-afterburning turbojets with a take-off rating at 20,000 kgp, a maximum cruise rating of 5,000 kgp and a minimum cruise rating of 3,000 kgp at the same speeds and altitudes.

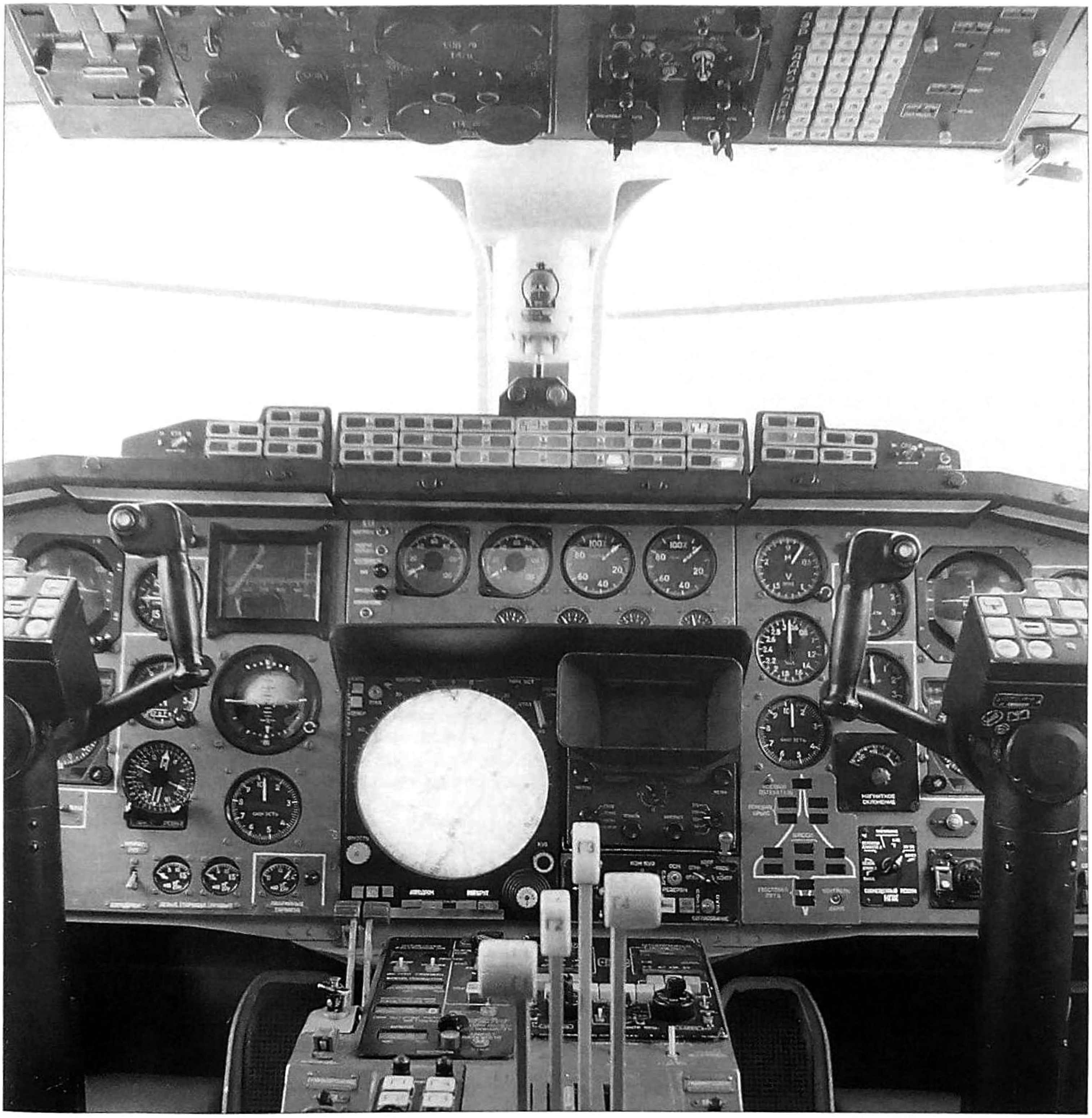
The RD36-51A is a single-shaft turbojet with a fixed-area air intake, a 14-stage compressor featuring a supersonic first stage and anti-vibration snubbers on the first three stages, an annular combustion chamber with multiple burners, a three-stage turbine and a variable nozzle. Nozzle area is adjusted by a cropped conical centrebody which translates in accordance with the throttle setting by means of a hydraulic ram. The centrebody is perforated and compressed air is forced into the exhaust jet through the perforations for noise attenuation purposes.

Construction is mostly of titanium. The air intake assembly has a fixed spinner and six angled struts. To minimise the space required for the engine the accessory gearbox is installed separately (on the airframe) and driven by an extension shaft via an intermediate gearbox off the engine shaft or the an air turbine starter. The latter is powered by compressed air separately from the engine.

EPR at sea level 15.8. Turbine temperature 1,355°K. SFC 0.882 kg/kgp·hr at take-off power, 1.23 kg/kgp·hr at maximum cruise rating and 0.94 kg/kgp·hr at minimum cruise rating. Length overall 5.976 m (19 ft 7$^{9}/_{32}$ in). Inlet diameter 1.486 m (4 ft 10½ in). Dry weight 3,900 kg (8,600 lb).

The engine is started, using compressed air supplied by the APU, ground supply or cross-feed from the other engines. Engine starting is automatic, once the sequence has been initiated.

On both versions the engines are housed in paired nacelles located under the wing centre section close to the fuselage. Each pair of engines breathes through two-dimensional supersonic air intakes separated by a vertical splitter and featuring three-segment horizontal airflow control ramps. To prevent boundary layer ingestion the intakes are set apart from the wing undersurface so that their upper lips act as boundary layer splitter plates, with a V-shaped fairing spilling the



The main instrument panels of a production Tu-144 with the circular navigation display and the radar display in the centre and keypads on the control wheels.

boundary layer; additionally, the airflow control ramps are perforated for boundary layer suction. Further downstream the inlet duct cross-section changes to circular at the compressor face; the inlet ducts are curved to provide room for the mainwheel well located ahead of the engines. The engine bays are separated by firewalls and air-cooled.

The air intake assembly for each pair of engines is manufactured as a single unit made of titanium and heat-resistant aluminium alloys; the air intake leading edge incorporates a de-icer. Each inlet duct features four spring-loaded auxiliary blow-in doors (three lateral ones and one ventral) used at low speeds and a single bleed door which opens in cruise flight to spill excess air. The inlet duct section changes from rectangular to oval with the bigger axis vertical (in the area of the wheel wells) to circular (at the engine compressor faces). The airflow control ramps and the spill door are controlled by an automatic air intake control system. This comprises an SU39-4 ramp and spill door automatic control system, an SIOD-3 pressure ratio measurement system (*sistema izmereniya otnosheniya davleniya*), a system feeding inputs from the pitot heads and static ports to the pressure sensors of the SU39-4 and SIOD-3, and the hydraulic actuators.

A Stoopino Machinery Design Bureau TA-6F APU is installed in the starboard engine nacelle ahead of the mainwheel well for self-contained engine starting, ground AC/DC power supply and air conditioning. The APU can be used as an emergency source of

electric power and compressed air (notably for the turbine-driven hydraulic pumps) in flight at up to 3,000 m (9,840 ft). The APU control panel is on the flight engineer's left-hand control console.

Control System: The combined electro-hydraulic control system provides for the following control modes:

- manual control throughout the flight;
- automatic climbout from the point of origin, flight along the designated route, descent and circuit flight at the destination airfield, using inputs from the NK-144 navigation suite;
- landing approach and go-around in automatic or flight director mode in ICAO Cat II weather minima (decision altitude 30 m/100 ft, horizontal visibility 400 m/1,300 ft);
- automatic stabilisation of barometric altitude, pitch, heading, indicated airspeed, Mach number and total temperature;
- alteration of pitch, heading, indicated airspeed and Mach number and execution of co-ordinated turns;
- automatic stabilisation and control of the aircraft in turbulence;
- presentation of flight/navigation data.

The control system includes a hydromechanical control system for the elevons and rudder, the ABSU-144 automatic flight control system and the canard foreplane control system. The hydromechanical control system with irreversible hydraulic actuators in all three control channels deflects the elevons and rudder, using control inputs from the pilots, the AFCS and the SAB-4 automatic longitudinal trim system (*sistema avtomaticheskoy balansirovki*). It incorporates an artificial-feel feature providing adequate control column and pedal forces, regardless of the aerodynamic loads acting on the control surfaces. The actuators are powered by four separate hydraulic systems for maximum reliability and are connected to the control columns and rudder pedals by conventional mechanical linkages (push-pull rods and bellcranks) passing under the floor.

Pitch and roll control is provided by elevons, the outer wings divided into four sections for greater reliability and ease of handling at different speeds. Directional control is provided by a two-section rudder.

As already mentioned, the canard foreplanes are actuated by an electromechanical drive; the control handle is located on the central control pedestal.

The ABSU-144 is an integrated automatic flight control system comprising the SUU-144 stability and control system, the SAU-144 automatic control system, the STU-75 approach/landing system, the AT-6 autothrottle and the SVK-144 built-in test equipment. Working in concert with other systems and equipment, the ABSU-144 enhances stability and handling in manual control mode, enables automatic control as directed by the NK-144 navigation suite, landing approach and go-around in automatic or flight director mode and automatic or manual longitudinal trim. It also automatically stabilises the principal flight parameters and allows them to be altered, using the AFCS control panel. Flight and navigation data are displayed on the PKP-72-2 flight director, the PNP-72-5M artificial horizon and the US-I airspeed indicator.

Fuel System: The wings, rear fuselage and fin house a total of 16 integral fuel tanks (nine main tanks, four service tanks and three trim tanks). The total fuel load is 98,000 kg (216,050 lb). In addition to its primary purpose, the fuel system serves for maintaining the required CG position throughout the flight and cooling various systems components.

Each engine has its own service tank and associated group of main tanks; however, a cross-feed system enables each engine to draw fuel from any service tank. Each tank features three transfer pumps (two electric pumps and one jet pump). The refuelling, fuel transfer and fuel usage sequence is observed automatically; manual control is also possible. The fuel flow and the fuel status for each tank are monitored by means of RT-31 flow meters and the SUIT1-3 fuel metering system. The latter, together with the SU12-2 fuel status indicator, also serves for controlling the refuelling, fuel transfer and fuel usage sequence and calculating the aircraft's CG position.

The fuel tanks are pressurised via the vent system connected to the cabin's dynamic cooling system. Fuel jettison valves are provided in each service tank.

The Tu-144 has two standard pressure refuelling connectors in each mainwheel well. Filling a maximum fuel load takes no more than 20 minutes. Nitrogenated fuel is used; additionally, a supply of gaseous nitrogen is stored in 14 spherical 10-litre (2.2 Imp gal) bottles charged to 150 kg/cm² (2,133 psi) for pressurising the fuel tanks during descent from cruise altitude to 10,000 m (32,810 ft) because the dissolved nitrogen does not emanate too readily in these conditions.

Hydraulics: Four separate hydraulic systems, each with its own reservoir, for maximum reliability. Hydraulic power is provided by eight NP-103 variable-delivery plunger-type pumps (two on each engine), each system including two pumps driven by different engines, and by two TNU back-up pumps driven by air turbines (*toorbonasosnaya oostanovka*). All systems have a nominal pressure of 210 kg/cm² (3,000 psi).

The No.1 system powered by pumps driven by the Nos 1 and 2 engines operates the wheel brakes, control surface actuators and the back-up supply of the port engines' intake ramp actuators. The No.2 system (powered by different pumps driven by the same engines) operates the control surface actuators, the primary supply of the port engines' intake ramp actuators, the landing gear retraction rams, the longitudinal trim system's fuel transfer pumps and the wheel brakes. The No.3 system powered by pumps driven by the Nos 3 and 4 engines operates the control surface actuators, the primary supply of the starboard engines' intake ramp actuators, the nosewheel steering mechanism and the longitudinal trim system's fuel transfer pumps. Finally, the No.4 system (powered by different pumps driven by the same engines) operates the control surface actuators and the back-up supply of the starboard engines' intake ramp actuators. The two TNU turbine pump units cater for the Nos 2 and 4 hydraulic systems if all four engines fail.

Electrics: Three electric systems The primary electric system uses 200/115 V/400 Hz three-phase stable-frequency AC supplied by four 60-kVA brushless generators, one for each engine, driven via hydromechanical CSDs. The primary system is split into port and starboard halves powered by Nos 1/2 and Nos 3/4 generators respectively; each generator works independently and the pairs of generators may work in parallel. The generators are provided with appropriate voltage regulators and overload protection devices which disable a malfunctioning generator to prevent damage to the system. The APU features a 40-kVA AC generator providing back-up power for the primary system.

Any two engine-driven generators provide enough power to cater for all of the aircraft's equipment, except for the cabin lighting and galley equipment. For overload protection the primary electric system circuitry incorporates quick-action fuses.

Secondary 36 V/400 Hz three-phase AC is provided by two step-down transformers (main and stand-by), with a 500-VA AC converter fed by the DC batteries as a backup. 27 V DC power is supplied by four 6-kW rectifiers, plus a 12-kW DC starter/generator driven by the APU; back-up DC power is provided by lead-acid batteries. A ShRAP-500K DC ground power receptacle and a ShRAP-400-3F AC ground power receptacle are provided on the underside of the starboard engine nacelle.

Oxygen System: The Tu-144 has a stationary oxygen system using high-pressure gaseous oxygen for the flight crew (used for fighting fatigue or in the event of decompression) and a stationary oxygen system using low-pressure gaseous oxygen and featuring KP-67

breathing apparatus (*kislorodnyy pribor*) for the cabin crew. Portable breathing apparatus is provided for the passengers. Additionally, during the flight test phase the crew wore VKK-6 pressure suits (*vysotnyy kompenseeruyuschchiy kostyum* – altitude compensation suit) and GSh-6 full-face pressure helmets (*ghermoshlem*) allowing them to bail out safely at high altitude.

Nitrogen System: The nitrogen system is an ancillary system of the powerplant, controlling the fuel jettison valves and the engine bay cooling control flaps; it also pressurises the fuel tanks. The charging connectors also serve the nitrogen bottles used for emergency lowering of the nose visor, hydraulic system pressurisation and brake parachute deployment/release.

Air Conditioning & Pressurisation System: The forward and centre fuselage form a single pressure cabin pressurised and ventilated by engine bleed air. The air conditioning system ensures comfortable conditions for the crew and passengers in all flight modes and when the aircraft is parked or taxying. It is adjusted by the flight engineer to maintain the cabin temperature anywhere between 20° and 30°C (68-86°F).

The ACS is split into independent port and starboard halves, each with its own cooling turbine; they draw air from the port and starboard pairs of engines respectively. On the ground, air for the ACS is supplied by the APU or a mobile air handling unit plugged into a ventral connector. The ACS components are housed in the wing/fuselage fairing.

Cabin ventilation is performed by a decentralised air ejection system mixing the cabin air with fresh air. The air ejected from the cabin serves for cooling various systems and equipment components.

The Tu-144 utilises a dynamic heat insulation system used supersonic cruise. Air is forced through porous panels between the cabin wall lining and the fuselage structure, protects the cabin against the kinetic heating at high Mach numbers. Supersonic flight can be continued if one of the cooling turbines fails.

The pressurisation system automatically maintains the prescribed pressure depending on the flight altitude. The maximum pressure differential in cruise flight is 0.72 kg/cm² (10.28 psi). At cruise altitude the cabin pressure equals 2,400 m (7,870 ft) above sea level.

De-icing System: Electric (AC) de-icing on the engine air intake leading edges, pitot heads, static ports and flightdeck windshield. The air intake de-icers have a cyclic operating algorithm and a power consumption of some 30 kVA. The integral windshield de-icers consume another 20 kVA; the heated panes are provided with a temperature regulator to prevent cracking. The de-icers are activated by the flight engineer. Additionally, the windshield is equipped with wipers which can be operated when the aircraft is flying at speeds up to 500 km/h (310 mph). No de-icers on the wing and fin leading edges.

Fire Suppression System: Nine 8-litre (1.76 Imp gal) UBSh-8-1 fire extinguisher bottles (*oonifitseerovannyy ballon sharovoy* – standardised spherical [fire extinguisher] bottle) charged with 114V_2 grade chlorofluorocarbon are fitted for fighting fires in the engine nacelles and in the APU bay. A separate system featuring three 1-litre (0.22 Imp gal) UBSh-1-1 bottles fights fires inside the engines proper. Both systems have a three-stage operating algorithm. The first shot is triggered automatically by flame sensors, the second and third shots are fired manually at the discretion of the crew and activated by the flight engineer. Impact sensors are provided to trigger all nine UBSh-8-1 fire extinguishers automatically in a wheels-up landing, preempting a possible fire. Additionally, portable fire extinguishers are provided in the cabin and flightdeck.

An SSP-2A fire warning system (*sistema signalizahtsii pozhara*) with DS-1 flame sensors provides audio and visual warnings of fires in the engine nacelles and in the APU bay. The engines feature a separate SSP-11 fire warning system.

The design embodies features intended to lessen the risk of a fire or to stop the propagation of the fire, should it break out. The engine nacelles incorporate firewalls and heat shields; hydraulic and fuel lines and crucial control system components located in 'hot' areas are made of heat-resistant steel. Non-flammable or low-combustible materials are used for the cabin structures (such as partitions or baggage bins), trim and fittings.

Avionics and Equipment: The Tu-144 is fully equipped for poor-weather day/night operation in all regions of the world, including automatic flight along pre-programmed routes and landing in ICAO Cat II weather minima.

Navigation and piloting equipment: The Tu-144 has an NK-144 navigation suite (*navigatsionnyy kompleks*) enabling domestic and international flights in any geographical conditions, including flights over large stretches of water. The suite is automatic, obviating the need for a navigator. Together with the AFCS the NK-144 enables the aircraft to follow a pre-programmed route. To this end, airway layouts and the coordinates of waypoints, airfields and radio beacon frequencies/locations are entered into the navigation computer. The system automatically calculates the aircraft's position, using inputs from autonomous navigation equipment – the Roomb-II (Compass Point) inertial navigation system and DISS-7 Doppler speed/drift sensor system (*doplerovskiy izmeritel' skorosti i snosa*) – and makes course corrections, using the RSBN-8S short-range radio navigation system (*rahdiotekhnicheskaya sistema blizhney navigahtsii* – SHORAN), the Koors-MP2 (Heading) compass system and the SDK-67 distance measuring equipment. The crew can enter the aircraft's coordinates and wind parameters manually (for instance, to make corrections for an unexpected headwind). All navigation parameters are displayed by the onboard instrumentation.

The NK-144 comprises the following components:

- a TsVM10-TS-144 digital computer (*tsifrovaya vychislitel'naya mashina*);
- a VPNK-154 navigation processor (*vychislitel' pilotazhno-navigatsionnovo kompleksa*);
- a Roomb-II INS;
- a DISS-7 Doppler speed/drift sensor system complete with a V-144V processor and an I-144 display;
- a duplicated SVS-P-72-3-1 air data system (*sistema vozdooshnykh signahlov*) with an altitude comparator module;
- a duplicated RSBN-8S SHORAN;
- a duplicated Koors-MP2 compass system;
- an SDK-67 DME kit;
- a K12 gyroscope;
- a PINO-12 navigation head-up display (*proyektsionnyy indikahtor navigatsionnoy obstanovki*);
- a UUT-144 pitch angle indicator (*ookazahtel' oogla tangazha*);
- an IVR climb/descent indicator (*indikahtor vertikahl'nykh rezheemov* – 'vertical modes indicator');
- an ARK-15 automatic direction finder (*avtomaticheskiy rahdiokompas*);
- control panels.

The NK-144 suite is linked to the ABSU-144 AFCS, the SOM-64 and SOM-70 transponders, the SUIT1-3 fuel metering system and the VK-90 correction switch.

Additionally, the Tu-144 is fitted with the following autonomous navigation equipment/flight instrumentation: an AGR-72 artificial horizon with a VK-90 correction switch, an AUASP-21KR automatic AOA/speed/G load limiter (*avtomaht ooglov atahki, skorosti i peregroozki*), a VKR-S dangerous flight mode computer (*vychislitel' kriticheskikh rezheemov*), VAR-30 and VAR-75 vertical speed indicators (the latter is used during emergency descent only; VAR = *variometr*), VT-25 and VTF-8000 altimeters (the latter calibrated in

feet), a duplicated RV-5 radio altimeter (***rah**diovysotomer*), US-1600 and UNSM-I airspeed indicators (*ookazahtel' **skorosti***), a PZVE flight level setting panel and a TS-4 warning/caution light panel (***tablo** signalizahtsii*). These are installed on the pilots' and flight engineer's instrument panels.

A Groza-144A weather radar is installed in the drooping nose visor. It is capable of detecting ground objects at a maximum range of 350 km (217 miles).

Communications equipment: The Tu-144 has a Mikron communications/command link HF radio, a Landysh-20 (Lily of the valley) UHF radio and an SPGS-1 speakerphone intercom (*samo**lyot**naya peregovornaya **grom**kogovo**rya**shchaya si**ste**ma*). An RI-65B automatic voice annunciator (*reche**voy** infor**mah**tor*) warns the crew of critical failures (such as fire) and dangerous flight modes.

IFF system: SRO-2M Khrom IFF transponder (*samo**lyot**nyy **rah**diolokatsi**on**nyy ot**vet**chik* – aircraft-mounted radar [IFF] responder). The aircraft also features SOM-64-144 (*samo**lyot**nyy ot**vet**chik mezhduna**rod**nyy* – lit. aircraft-mounted international responder) and SO-70-144 ATC transponders. These transmit the aircraft's registration, speed and altitude for presentation on ATC radar displays and may operate in 'Mayday' mode.

Data recording equipment: MSRP-12-96 flight data recorder and MS-61B cockpit voice recorder. The FDR captures 12 parameters, including barometric altitude, indicated airspeed, roll rates, vertical and lateral G forces, control surface deflection and throttle settings, as well as gear/flap transition and so on.

Specifications of the Tu-144 (*izdeliye* 004)

Length overall	65.7 m (215 ft $6\frac{39}{64}$ in)
Fuselage length	64.45 m (211 ft $5\frac{13}{32}$ in)
Fuselage diameter	3.5 m (11 ft $5\frac{3}{4}$ in)
Wing span	28.0 m (91 ft $10\frac{23}{64}$ in)
Height on ground	12.5 m (41 ft $0\frac{1}{8}$ in)
Wing area, m² (sq ft):	
with LERXes	507 (5,451)
less LERXes	433 (4,656)
Landing gear track	6.05 m (19 ft $10\frac{3}{16}$ in)
Landing gear wheelbase	19.63 m (64 ft $4\frac{27}{32}$ in)
Cabin cross-section	3.03 x 1.95 m (9 ft $11\frac{19}{64}$ in x 6 ft $4\frac{49}{64}$ in)
Cabin volume (total), m³ (cu ft)	185 (6,533)
Flightdeck volume, m³ (cu ft)	10.1 (356)
Baggage compartment volume (total), m³ (cu ft)	21.1 (745)
Empty weight, kg (lb)	91,800 (202,380)
Operating empty weight, kg (lb)	92,700 (204,365)
Equipment weight, kg (lb)	900 (1,980)
Normal take-off weight, kg (lb)	180,000 (396,825)
Maximum take-off weight, kg (lb)	195,000 (429,900)
Maximum landing weight, kg (lb)	120,000 (264,550)
Fuel load, kg (lb)	98,000 (216,050)
Payload, kg (lb)	13,000-15,000 (28,660-33,070)
Seating capacity	150
Cruising speed, km/h (mph):	
supersonic cruise	2,000-2,350 (1,242-1,459)
subsonic cruise	950 (590)
Normal cruise altitude, m (ft):	
supersonic cruise	16,000-18,000 (52,490-59,050)
subsonic cruise	8,000-10,000 (26,250-32,080)
Average fuel consumption, kg/km (lb/mile):	
supersonic cruise	18 (63.8)
subsonic cruise	16 (56.7)
Average fuel consumption, tonne/hr (lb/hr):	
supersonic cruise	39 (85,980)
subsonic cruise	15.2 (33,510)

Tu-144 Performance

	Supersonic cruise	Subsonic cruise
Range, km (miles):		
overall	3,240 (2,012)	4,300 (2,670.8)
acceleration/climb phase	760 (472)	170 (105.6)
cruise phase	2,100 (1,304)	4,000 (2,484.4)
deceleration/descent phase	380 (236)	130 (80.75)
Fuel burn, kg (lb)	78,300 (172,620)	78,300 (172,620)
Endurance	2 hrs 12 min	4 hrs 55 min
Required runway length at sea level, ISA, m (ft)	n.a.	3,050 (10,000)

Accommodation: The flightdeck is configured for a crew of three – two pilots and a flight engineer. The cabin crew comprises four flight attendants.

In the baseline 150-seat mixed-class configuration the Tu-144 has two cabins separated by the No.2 galley. The forward cabin is divided by a partition into a first-class cabin seating 16 and a tourist-class cabin seating 30; the rear cabin offers tourist-class accommodation for 104 passengers. The first-class cabin has four-abreast seating at 102 cm ($40\frac{5}{32}$ in) pitch; the seat backs can recline up to 45°. The tourist-class cabins have five-abreast seating at 87 cm ($34\frac{1}{4}$ in) pitch with an aisle offset to port. All cabins feature enclosed overhead baggage bins.

The first and second entry vestibules house the two galleys, as well as coat closets and toilets; they also provide accommodation for the cabin crew on dual jump seats. One more toilet is located at the end of the rear cabin; each of the three toilets has its own water supply system and septic tank. The cabin, vestibule and toilet walls are upholstered in non-flammable synthetic materials and the floor is covered with a synthetic carpet having a foam rubber base.

Passenger evacuation in an emergency takes place via the overwing emergency exits and the entry and service doors. All four doors feature inflatable escape slides; the onboard emergency kit includes escape ropes and axes for chopping through the fuselage skin if the regular exits are unusable. For overwater flights the aircraft is provided with five inflatable rafts equipped with survival kits and SOS radio beacons, as well as with life vests for all occupants.

The flight performance figures stated in the upper table on this page were recorded on an NK-144A powered Tu-144 *sans suffixe* in 1975.

The lower table shows the Tu-144's performance with a 195-tonne TOW, a 14-tonne (30,860-lb) payload and 10-tonne (22,045-lb) fuel reserves.

Chapter 4

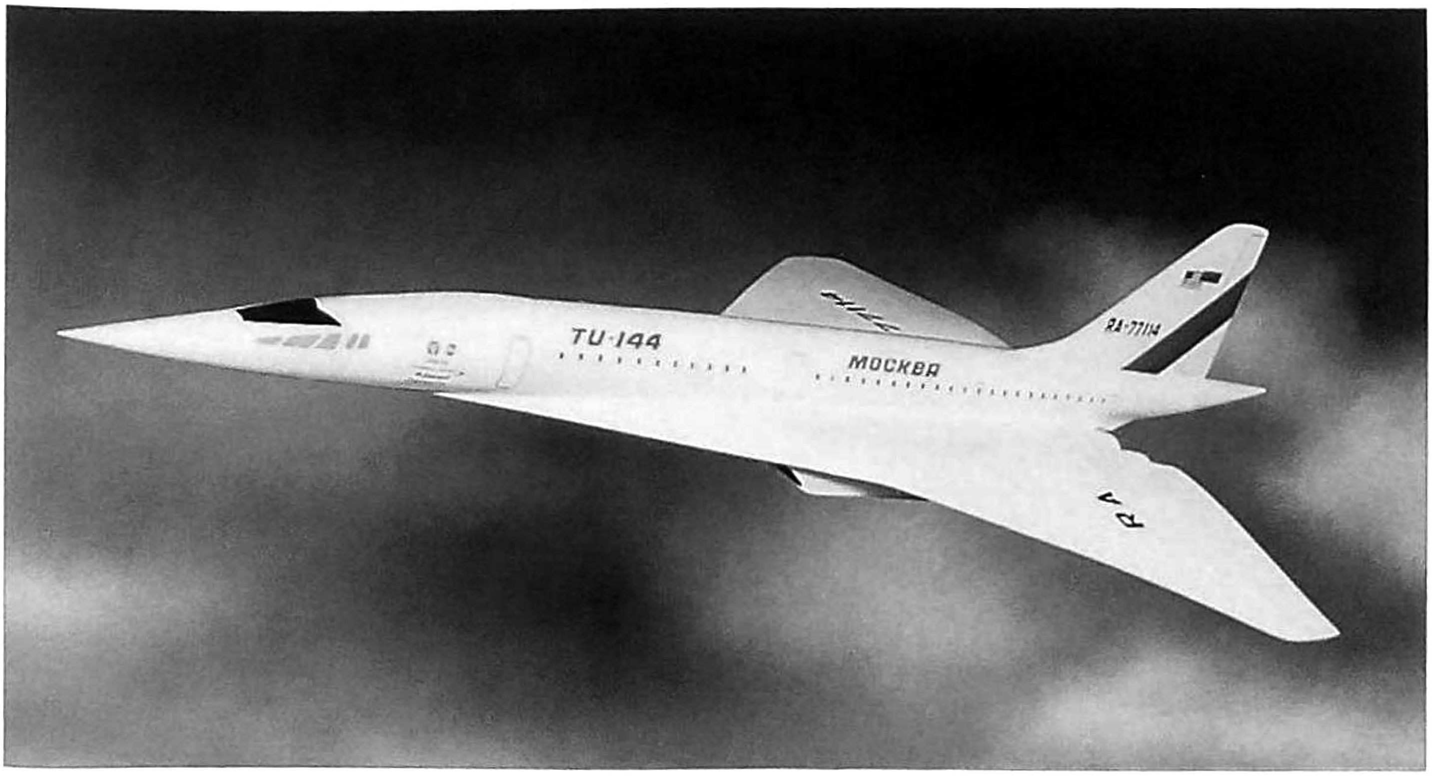
International Co-operation

The beginning of actual co-operation between Russia and the Western world in the field of aviation technology dates back all the way to the days of the First World War, when Russian factories produced several types of French combat aircraft under licence. These aircraft were flown in combat against a common enemy, Kaiser Wilhelm II's Germany and Austro-Hungary, by several Imperial Russian Air Fleet pilots who later became prominent specialists of the Tupolev OKB – N. I. Petrov, Ye. I. Pogosskiy, A. A. Rosenfeld, Ye. K. Stoman and A. M. Cheryomukhin.

When the Bol'sheviks seized power in October 1917, they continued purchasing Western aircraft in sizeable quantities for a while. These aircraft were operate by the Red Army Air Force and the Civil Air Fleet (Aeroflot and its subsidiaries) and were carefully examined by the Soviet aircraft designers wishing to learn from their Western colleagues. As the Soviet Union proceeded with its first five-year economic development plans, manufacturing licences were obtained for French (Renault and Gnome-Rhône), American (Wright and Ford), British (Bristol) and German (BMW) aero engines which powered Soviet-designed aircraft for many years and laid the foundation for the national aero engine design practice. During the Second World War thousands of American and British warplanes delivered under the Lend-Lease agreement fought alongside indigenous designs to defeat Nazi Germany's war machine in the skies of the Soviet Union and Eastern Europe. In the immediate post-war years, the delivery of Rolls-Royce Nene I and Derwent V turbojets and their subsequent licence production in the USSR made it possible to create such outstanding combat aircraft as the Mikoyan/Gurevich MiG-15 and MiG-17 fighters, Il'yushin IL-28 and Tupolev Tu-14 tactical bombers.

The long-standing and effective partnership between the Tupolev OKB (ANTK Tupolev) and Aérospatiale began at the 27th Paris Air Show in 1965 where both companies unveiled the projects of their future SSTs – the Tu-144 and the Concorde. Displayed at Le Bourget in model form, the two aircraft had far more in common with each other than they had with American SST projects (the Boeing 2707 and others). At the show, Aérospatiale President Henri Ziegler and the Concorde's chief designer Pierre Sartre had talks with the Soviet Union's Minister of Aircraft Industry Pyotr V. Dement'yev and General Designer Andrey N. Tupolev; the parties agreed on Soviet-French co-operation in the service introduction of the Tu-144 and the Concorde. A few years later, Aérospatiale and the Tupolev OKB were assigned responsibility for the practical steps aimed at such co-operation.

After several meetings at the managerial level, when both companies' chief executives and high-ranking design staff had a chance to examine the factories at which their counterparts' aircraft would be produced, working meetings between the engineers doing the actual design work on the Tu-144 and the Concorde started taking place on a regular basis from 1971 onwards. Actually the basis for practical co-operation had been established at the 28th Paris Air Show in 1967 when



A model of the Tu-144LL research aircraft used in the efforts to create a second-generation SST. The aircraft is named *Moskva* (Moscow).

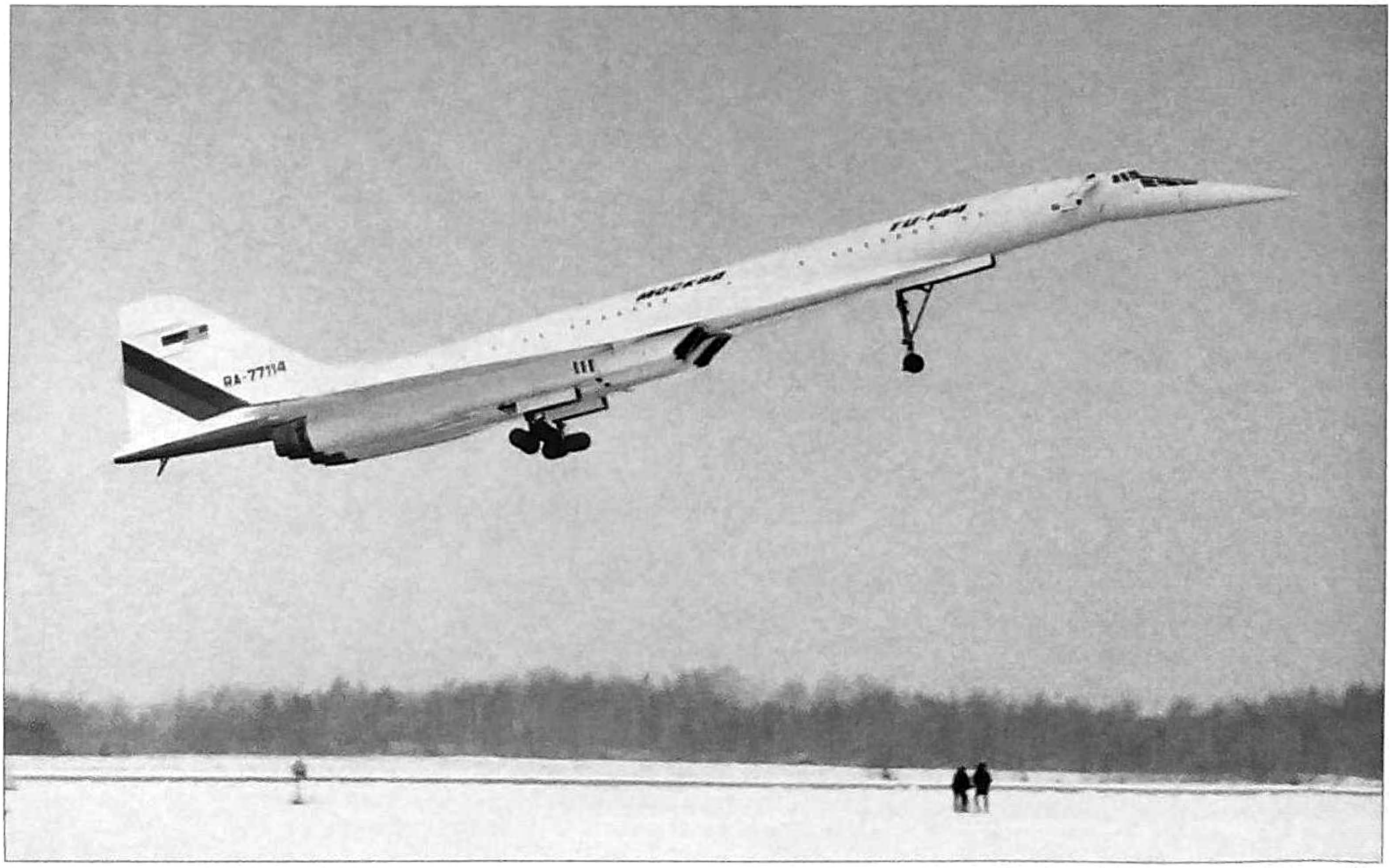
Above: Seen from the roof of one of ANTK Tupolev's hangars at Zhukovskiy, the as-yet nameless Tu-144LL is seen during its roll-out ceremony in November 1996. The long nozzles of the NK-321 engines are clearly visible; note another Tu-144 and a Tu-160 in the background.

The white-painted Tu-144LL certainly looks impressive sitting under stormy skies at the Zhukovskiy flight test facility.

Above: The Tu-144LL sits on the taxiway at Zhukovskiy after being towed into position by a KrAZ-255B 6x6 lorry, with an SPT-104 electrically powered gangway positioned near the forward entry door. Note the logos of the programme's participants aft of the flightdeck.

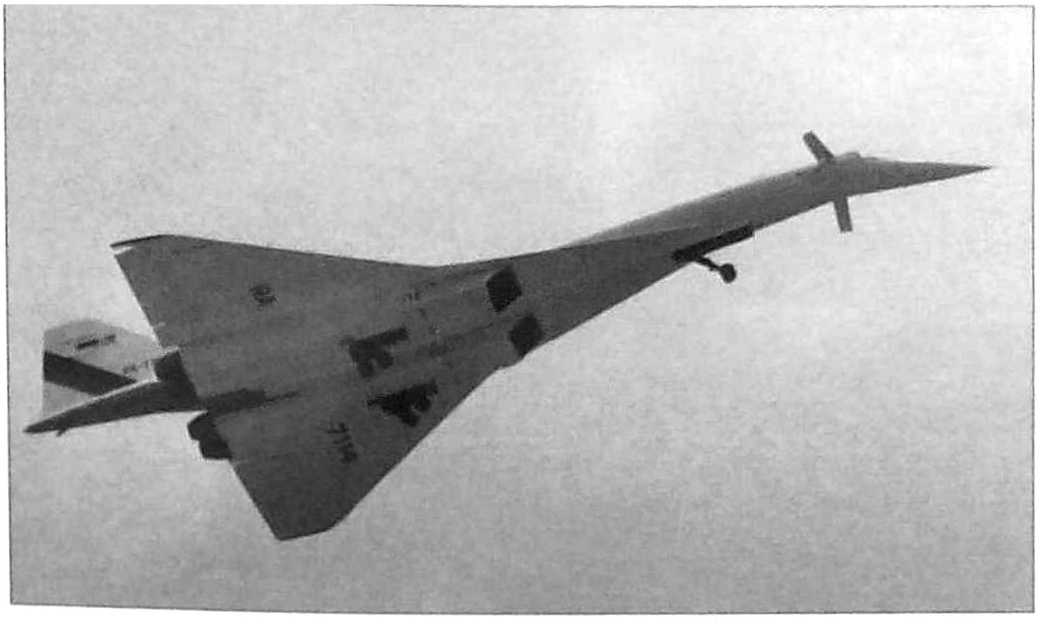
Nose drooped and canards deployed, the Tu-144LL prepares to taxi.

Above: RA-77114 streams vortices from the wings as it becomes airborne from runway 12 at Zhukovskiy. The huge 'beach ball' in the background houses the airfield's approach radar.



Another test flight in a winter setting.

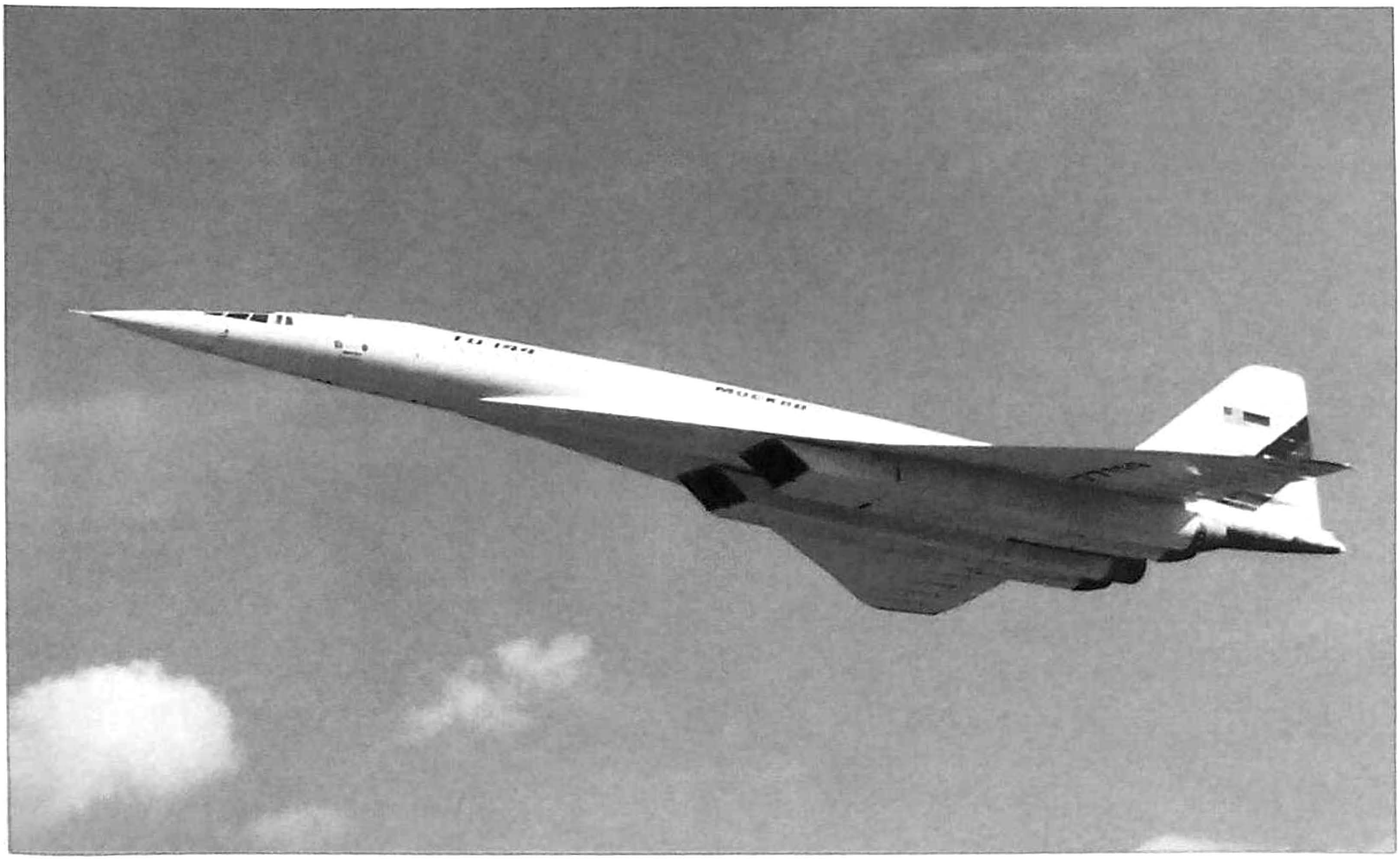
Pierre Sartre arranged a meeting between Aérospatiale's and Tupolev's chief project aerodynamicists, Fage and Cheryomukhin. At subsequent meetings the Tupolev engineers, obeying instructions from their top brass, would tell their French colleagues *how* they were working but withhold the information on *what* they had achieved. The French did just the opposite – they spoke freely of the results but would not tell how they had been achieved. Gradually, as the two design teams got to know each other better, the French engineers realised that 'the Russians' would eventually guess the 'how' while the Soviet engineers conceded that the French colleagues would see the 'what'. Thus, both sides concluded that there was no point in playing hide-and-seek and started sharing information freely, thus aiding each other immensely. For instance, Aérospatiale showed a keen interest in the Soviet technologies of sealing and repairing the fuel system (the amount of fuel leaking from the Tu-144 on the ground was almost ten times less than the Concorde's) and in the Soviet heat protection coatings. The Tupolev OKB engineers, in turn, were interested primarily in the methods of proving the aircraft's compliance to current airworthiness standards. Speaking of which, to facilitate co-operation the Soviet and French delegations undertook a lot of joint work on comparing selected chapters of Soviet and Anglo-French airworthiness regulations.



Above: The Tu-144 climbs away with the landing gear in mid-retraction. The canards are apparently starting to retract as well.

This openness in the interaction between engineers was a thorn in the side for the leaders of the Tupolev OKB and Aérospatiale alike; both companies held the view that they were giving away more than they were receiving. Yet, realising that the Tu-144 and the Concorde would not be direct competitors (being designed for different markets) but had the potential to become 'partners' helping to resolve each other's technical problems, the Soviet and French designers kept widening the scope of the joint work. Eventually the top brass had to back down.

French engineers gave detailed information on the course of scheduled transatlantic Concorde flights, not withholding information on incidents (including the first instance when a landing gear wheel disintegrated).



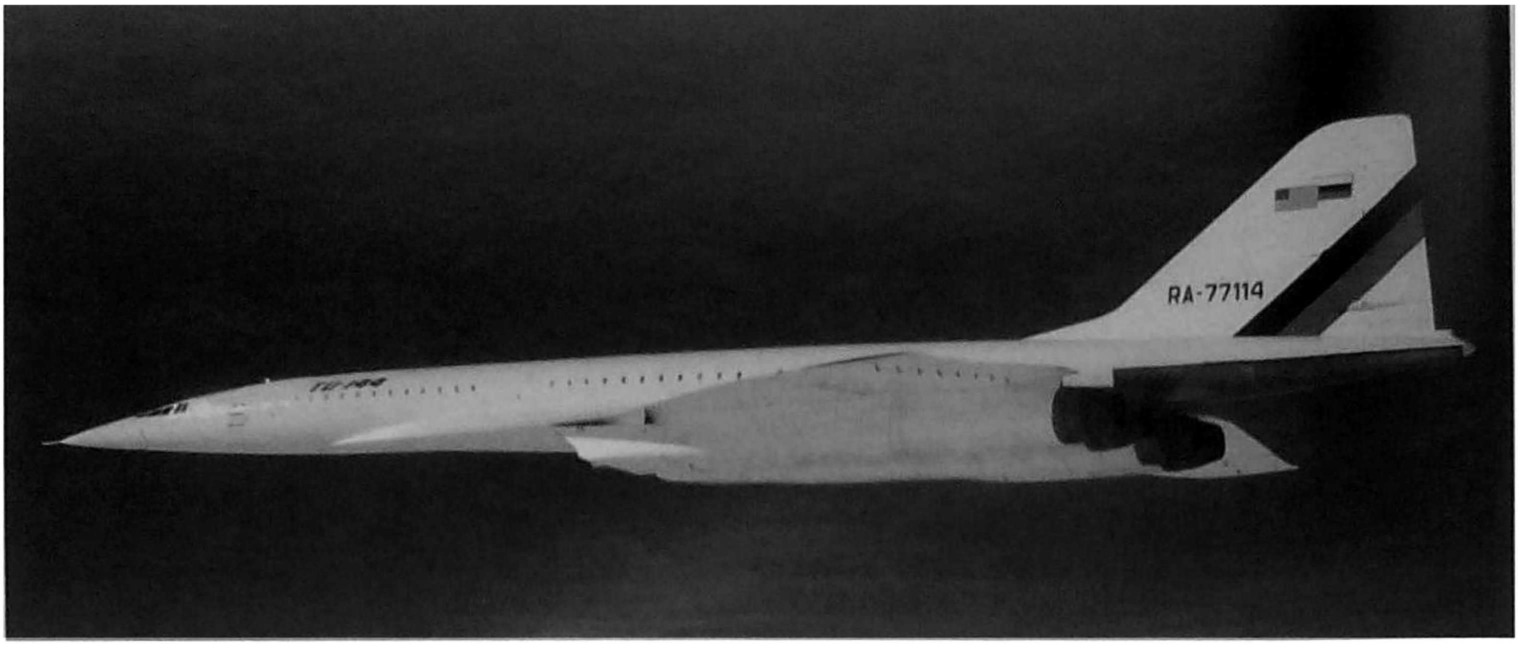
White Thunder. The Tu-144LL makes a high-speed flypast in cruise configuration.

Above: The Tu-144LL on finals to Zhukovskiy. Oddly, the canards are still retracted and the elevons are not drooped.

Brake parachutes billowing in the engine exhaust, RA-77114 leaves runway 30 at Zhukovskiy opposite the Myasishchev OKB facility.

Above: Seen from the control tower at Zhukovskiy, the Tu-144LL accelerates down runway 12. The ANTK Tupolev test facility's hardstand crammed with assorted bombers is in the background across the old runway 08/26, which is used as the static display area during Moscow airshows.

Seen moments after touchdown on runway 30, the Tu-144 streams its three cruciform brake parachutes.



A fine shot of the Tu-144LL travelling at supersonic speed taken from a fighter used as a chase plane.

In this way they hoped to assist their Soviet colleagues in ensuring Tu-144 operations on the Moscow-Alma-Ata service. Eventually the cessation of Tu-144 operations and the fact that the Concorde was operated on just two routes (Paris-New York and London-New York) killed the prospects for any further development of the first-generation SSTs. Still, the interest in a second-generation successor lived on. Eventually, however, the insurmountable hurdle turned out to be not of a technological nature – it was the environmental issues (primarily the sonic boom and its effect on all living creatures) which environmental protection crusaders hyped up to such a degree that flights of SSTs over land were banned altogether. An international association known as the Group of Eight, comprising the Boeing Commercial Airplane Group, McDonnell Douglas, British Aerospace, Aérospatiale, Deutsche Aerospace, (as part of the Airbus Industrie consortium), Alenia, an association of Japanese aerospace companies (Fuji Heavy Industries, Mitsubishi Heavy Industries, Kawasaki and others) and ANTK Tupolev, came to the conclusion that creating an affordable second-generation SST that would meet the new tough sonic boom limits was technically impossible. If the SST were to fly at subsonic speeds on the overland legs of the journey to avoid booming someone, it would have to have a non-stop range of some 12,000 km (7,450 miles) to be economically viable, which was likewise impossible for the time being. Thus all further attempt to create a successor to the Tu-144 and the Concorde were shelved for many years.

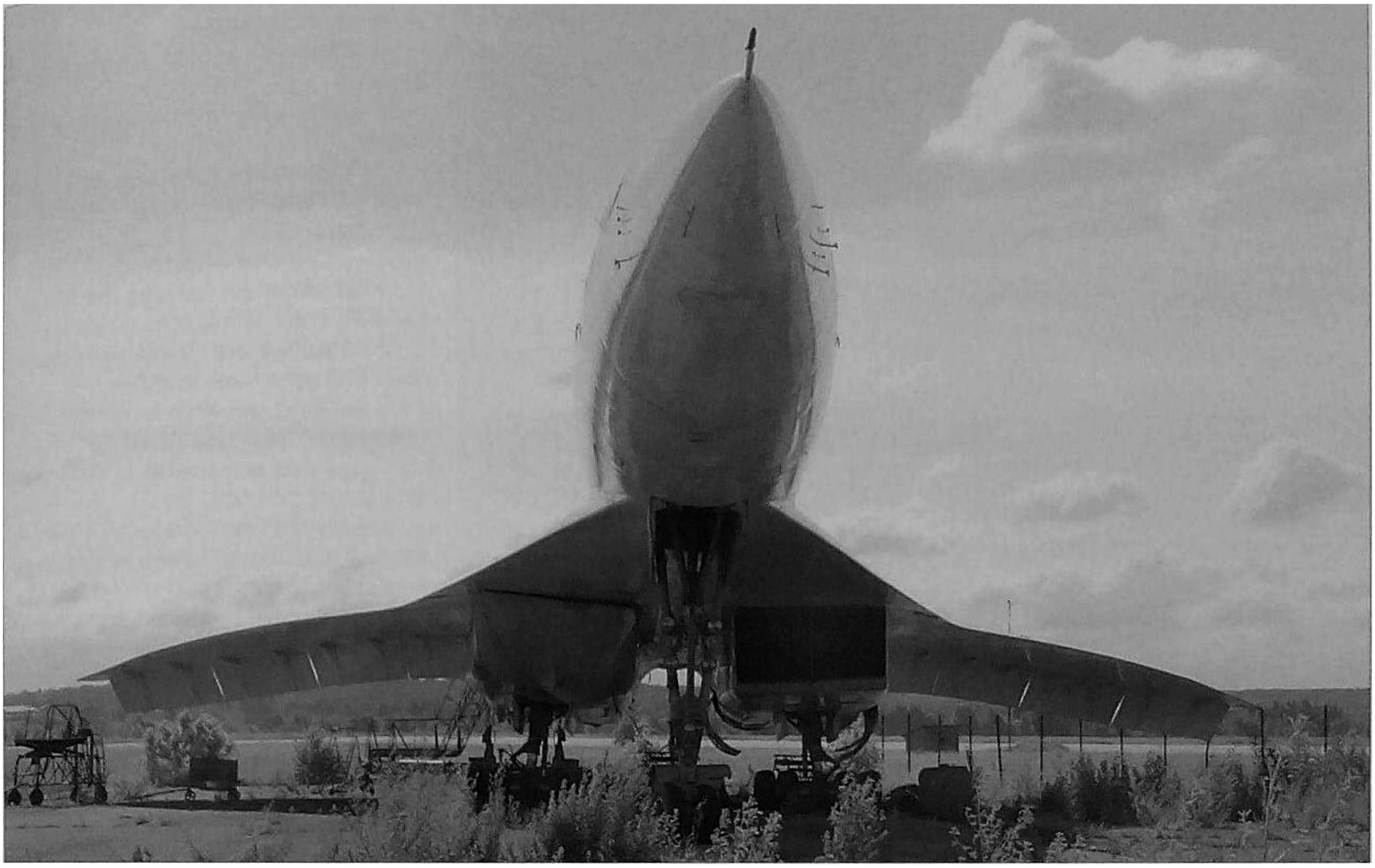
Since a supersonic airliner is an extremely expensive project, the design methods and actual design features that go into such an aircraft should be verified on flying testbeds if at all possible to reduce the technical risk. The larger the testbed aircraft is, and the closer its performance comes to the projected SST's design performance, the more valuable it becomes in its research capacity. Such complex issues as calculating the skin temperature of an integral tank filled with cold fuel in kinetic heating conditions, or calculating the heating intensity of the fuel being fed to the engines, can only be checked out in actual supersonic flight which will yield as authentic a result as you can possibly get, allowing errors in calculation methods to be corrected. This is why in the early 1990s the Tupolev OKB started work on a research aircraft designated Tu-144LL (*letayuschchaya laboratoriya* – lit. 'flying laboratory') and intended to provide data for the possible SST-2. Incidentally, the term *letayuschchaya laboratoriya* is used indiscriminately for any kind of testbed (avionics, engine, equipment, weapons), an aerodynamics research aircraft or control configured vehicle, a weather research aircraft, a geophysical survey aircraft and so on.

Working hard and persistently, by 1993 the ANTK Tupolev engineers had finalised the Tu-144LL's outlook and completed a set of drawings for the modification job. At the 40th Paris Air Show in June of that year ANTK Tupolev and the US company Rockwell International struck the first international co-operation agreement concerning development of the Tu-144LL research aircraft.

At that point ANTK Tupolev had three Tu-144Ds remaining in flyable condition – CCCP-77112, CCCP-77114 and CCCP-77115. Two further examples present at the company's flight test facility in Zhukovskiy, CCCP-77105 and CCCP-77113, were no longer airworthy and were broken up shortly afterwards. CCCP-77114 was selected for conversion; CCCP-77112 was to serve as a ground test rig in support of the programme, while CCCP-77115 was in 'hot reserve'.

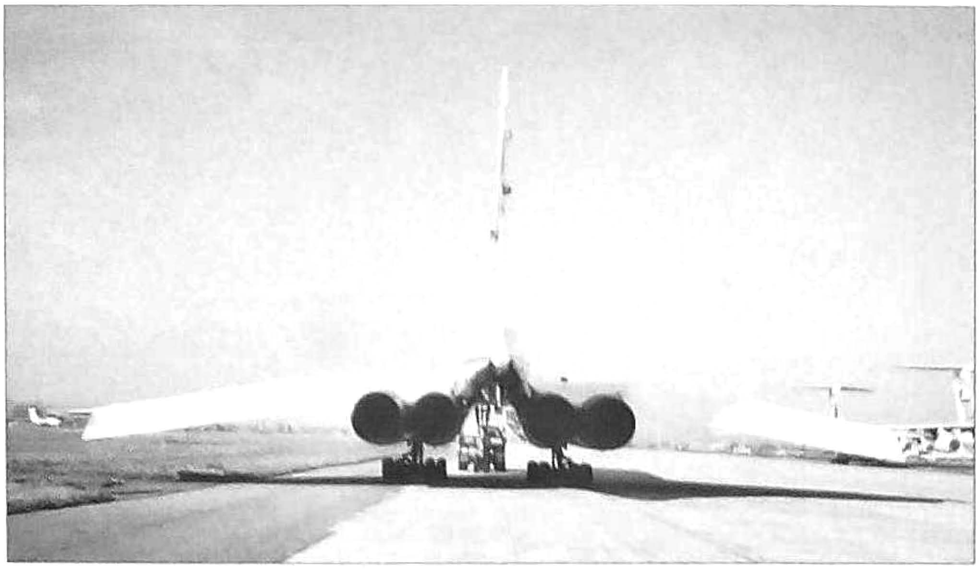
The Tu-144LL conversion involved primarily a change of powerplant: the Tu-144D's Kolesov RD36-51A non-afterburning turbojets gave place to Kuznetsov NK-321 afterburning turbofans, a version of the Tu-160's NK-32 engine rated at 13,000 kgp (28,660 lbst) dry and 25,000 kgp (55,115 lbst) reheat. This was a forced measure, as the RD36-51A engine custom-made for the Tu-144D was long since out of production and the surviving examples had a remaining service life of just a few dozen hours. The new engines necessitated manufacturing new rear portions of the engine nacelles and the inlet ducts, installation of additional equipment in the form of the ESUD-32-1 full authority digital engine control system (FADEC) and the SKSU-32-1 engine monitoring system, local wing reinforcement to take the more powerful engines and some changes to the aircraft's systems.

It has to be said that even when the Russian-US inter-government commission co-chaired by Prime Minister Viktor S. Chernomyrdin and Vice-President Albert L. Gore had passed documents giving the Tu-144LL official status, the aircraft remained the subject of a controversy. 'Why the Tu-144?', some people clamoured, 'Why not the Concorde?'. In the USA there was a powerful anti-Russian lobby which maintained that the funds allocated by the US Congress for the development of a supersonic research aircraft should not be given to Russia and that the Concorde should be used as the basis for this programme instead. In 1995, responding to these allegations, Louis Williams, head of NASA's High Speed Research Program, gave



Above: Head-on view of the Tu-144LL undergoing maintenance at Zhukovskiy.

Another aspect of the Tu-144LL. The aircraft's fate after the completion of the research programme remains undecided.



Above: A rear view of RA-77114 being towed along runway 08/26 which is no longer used as a runway but rather as a hardstand.

several interviews to the world's leading aviation magazines, explaining why the Tu-144 had been selected over the Concorde. The supersonic research aircraft should come as close as possible to the future SST-2 in size, performance and aerodynamic efficiency, said Williams, and gave figures to prove his point. The Tu-144's wing area was 507 m² (5,450 sq ft) versus the Concorde's 425 m² (4,570 sq ft); its cruising speed of Mach 2.35 (versus the Concorde's Mach 2.2) came closer to the SST-2's envisaged speed of Mach 2.4, and its lift/drag ratio at Mach 2.0 was 8.1 versus 7.3 for the Concorde.

The Tu-144 had a record share of titanium in its structure accounting for nearly 20% of the airframe weight, retractable canards and a unique wing/fuselage structural design. All this made it a better candidate than the Concorde.

The success of the Tu-144LL programme was in no small part due to good interaction between the partners. The organisational aspects were handled by IBP Corporation headed by Judith DePaul.

The conversion work took place in 1995 and 1996. Reregistered RA-77114 and wearing a white colour scheme with a blue/red stripe on the fin and Russian and American flags, the Tu-144LL made its first flight on 29th November 1996; the last flight took place on 28th February 1998. In the course of 27 test flights the aircraft participated in eight flight experiments. These were:

- defining the aircraft's temperature balance;
- exploring the basic aerodynamic parameters;
- exploring the temperature of the powerplant in different flight modes;
- exploring the influence of ground effect on low aspect ratio wings;
- assessing the aircraft's stability and handling;
- measuring the structure's acoustic loads and cabin noise levels;
- exploring the temperature fields in the fuel system;
- exploring the deformation of the wings in flight.

Additionally, two unique ground experiments associated with the powerplant were performed. These were:

- defining the optimum configuration of an advanced supersonic air intake as regards pressure ratio, airflow irregularity and pulsation;
- studying the integration of short supersonic inlets and the engines.

The results of the tests made it possible to evolve methods of calculating the thermal load, aerodynamics, acoustic load and so on for the next generation of SSTs and supersonic business jets.

The Tu-144LL was displayed at the MAKS-97 and MAKS-99 airshows in Zhukovskiy. On the latter occasion the aircraft wore the legend 'Moskva' (Moscow) on the fuselage.

After sitting idle for a while, the Tu-144LL has become a bit grubby, with dirty streaks running from the cabin windows.

Chapter 5

Next Generation

Later Tupolev SST Projects

Despite the curtailment of the Tu-144 programme in the early 1980s, the Tupolev OKB – known in post-Soviet days as the Tupolev Aviation Science & Technical Complex (ANTK Tupolev) or the Tupolev Public Limited Co. – did not give up on the idea of creating a viable supersonic airliner. The SST projects that followed the Tu-144 and were developed over the last 30 years are described here.

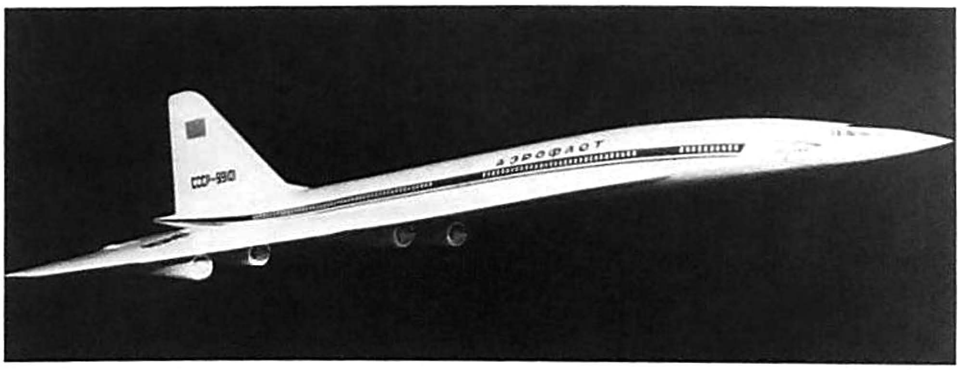
Tu-244 Second-Generation Supersonic Airliner (SST-2)

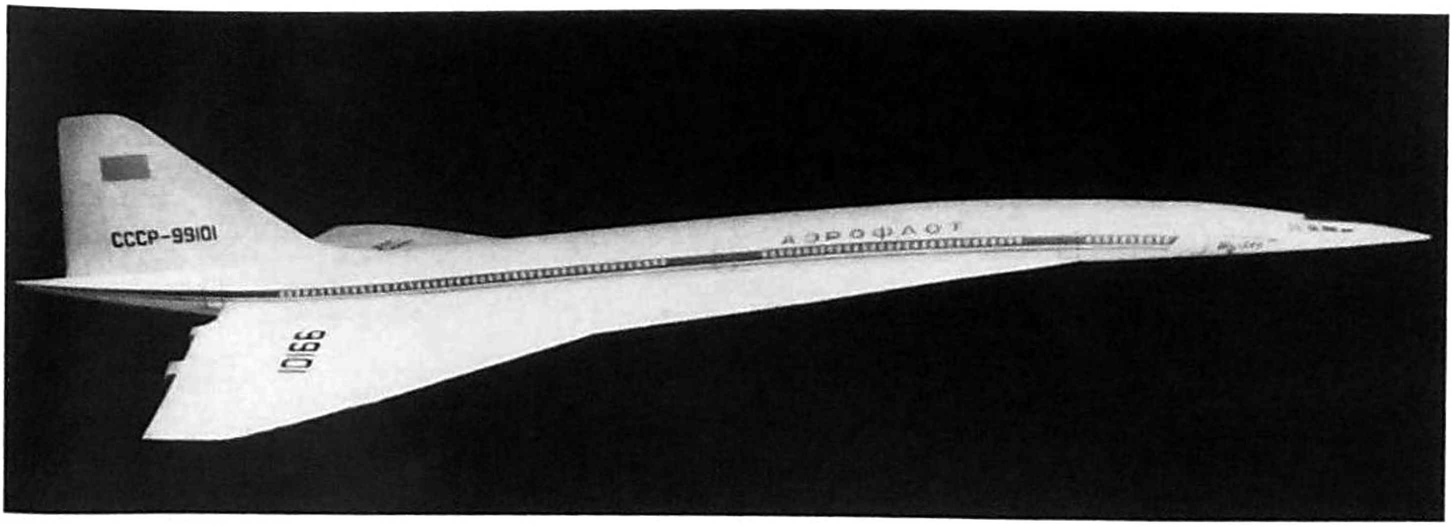
As early as the mid-1970s, when the work on the Tu-144 was still in progress, the Tupolev OKB began development of a future successor – a second-generation SST eloquently designated Tu-244. The programme itself was named SPS-2 (*sverkhzvookovoy passazheerskiy samolyot vtorovo pokoleniya* – second-generation supersonic airliner, or SST-2). In passing, such 'father-and-son' pairs of designations are not altogether uncommon in the Soviet Union and in present-day Russia. Examples include the Il'yushin IL-114 twin-turboprop regional airliner (a 'modern incarnation' of the 1950s-vintage IL-14 piston-engined airliner) and the projected Kamov Ka-115 light utility helicopter (a state-of-the-art 'reincarnation' of the Ka-15, another 1950s product).

This time the designers were facing a larger-scale task. The objective was not only to achieve scheduled supersonic passenger services but to compete viably with the most modern and sophisticated subsonic airliners of the day. This was to be achieved by attaining superior economic efficiency, reducing the environmental impact and offering enhanced passenger comfort. The SST-2 would provide the better economics by virtue of its higher operating efficiency, combining a higher seating capacity with supersonic cruising speed; thus a small number of SSTs would cope with the growing passenger traffic volumes better than a larger fleet of subsonic airliners. The resulting reduction in acquisition and operating costs of a smaller fleet would offset the airlines' greater outlays for fuel caused by the SST's thirstier engines.

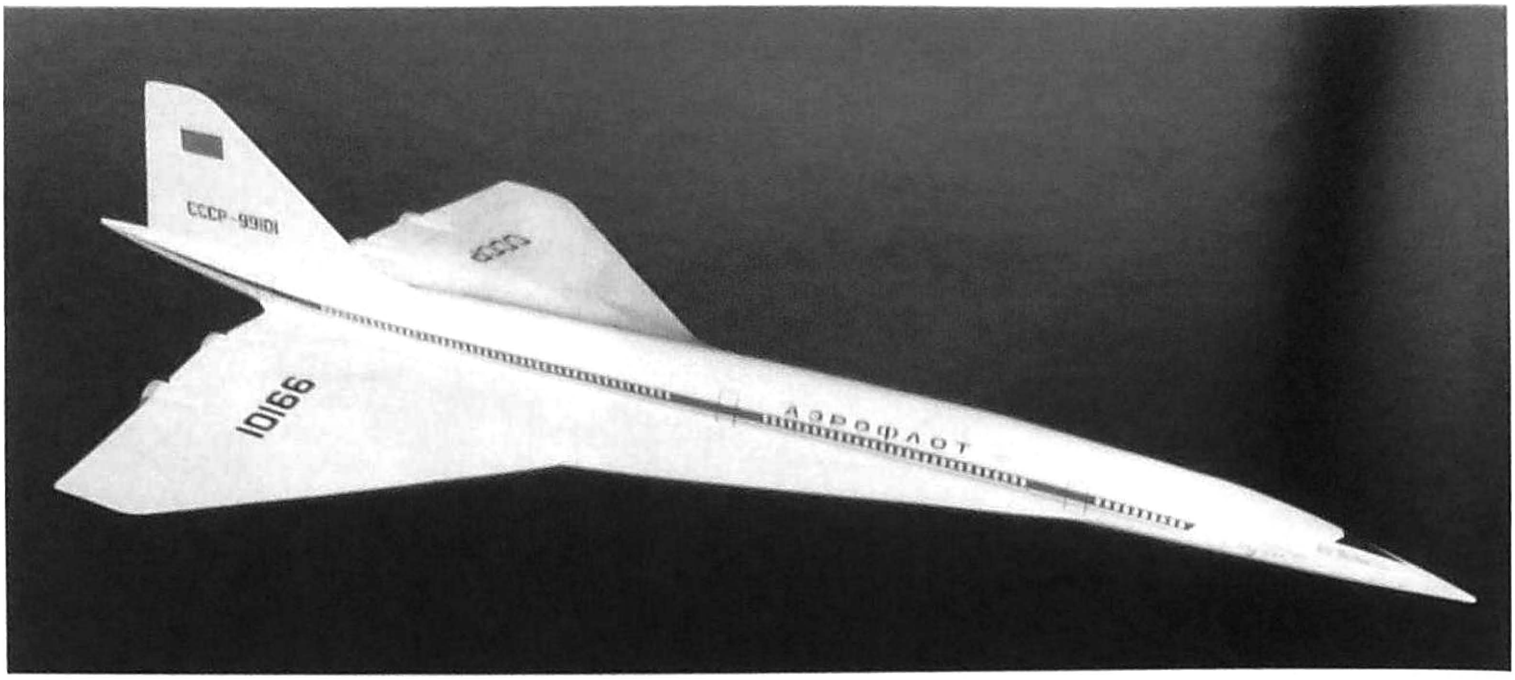
Taking due account of the experience they had accumulated with the SST-1 (the Tu-144), the Tupolev OKB engineers took great pains to address the environmental issues associated with the SST-2 – the sonic boom problem and the reduction of harmful emissions, especially with regard to ozone layer depletion. (The latter was important, since supersonic aircraft were perceived as being especially hostile to the ozone layer.) Of course, these issues had not exactly been brushed aside when designing the Tu-144, but they had lower priority then because the main objective was to beat the Western world to the target of putting a production SST into service.

Since the launch of the SST-2 programme the Tupolev OKB, assisted by the national aircraft industry's leading research establishments, has developed several consecutive versions of the Tu-244 project differing in aerodynamic layout, airframe design details, powerplant and target performance. The first of these resembled a scaled-up Tu-144 (*izdeliye* 004) but with the engine nacelles set farther apart (that is, farther from the fuselage, Concorde style). It was characterised by a





Top and above: This model depicts a late 1970s configuration of the Tu-244 second-generation SST featuring separate engine nacelles and axisymmetrical air intakes with conical centrebodies.

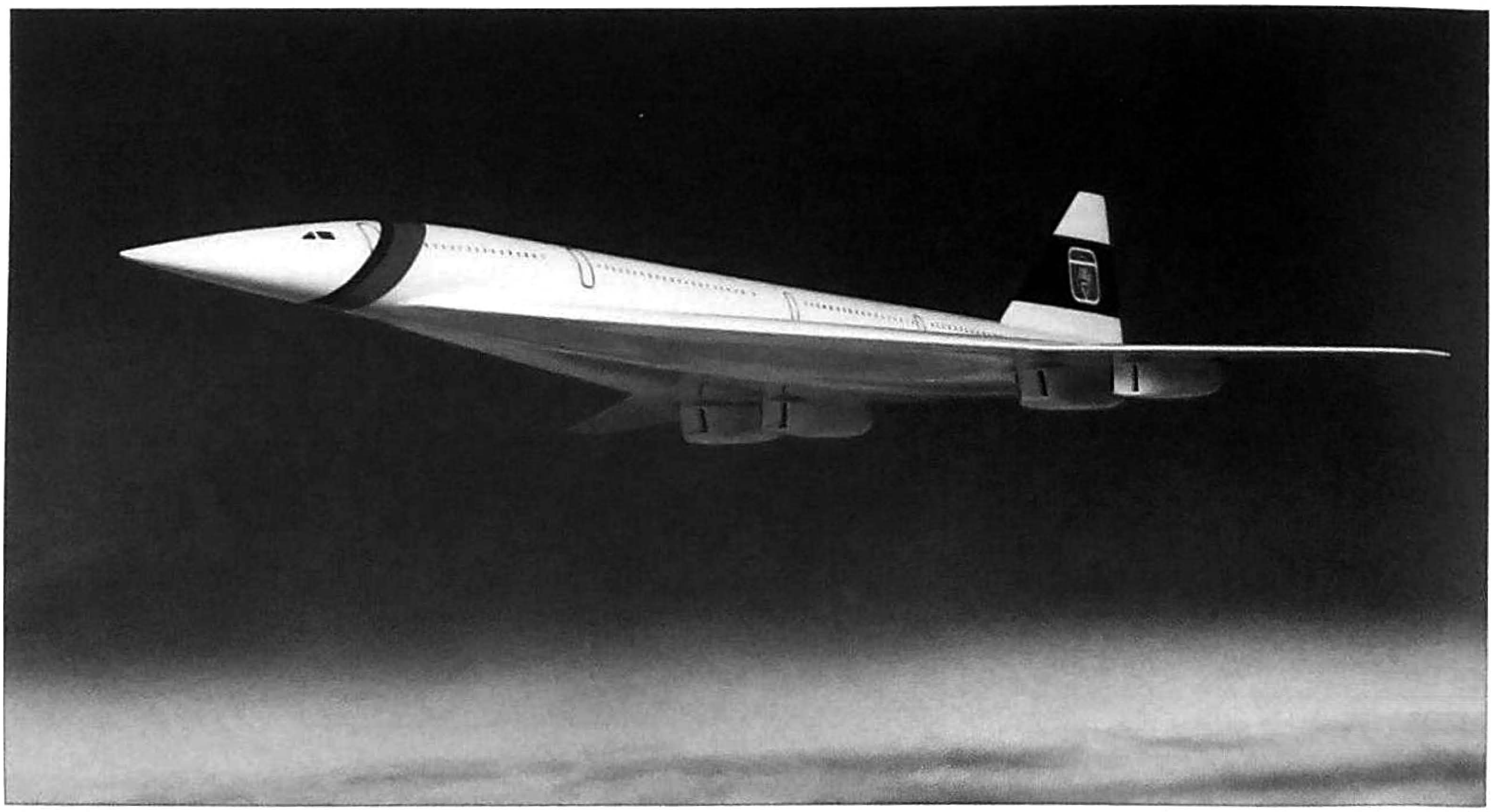


Above: Another view of the same model, showing the wing planform similar to that of the Tu-144, the similar nose glazing design and the elevon sections between the inboard and outboard engines

higher lift/drag ratio as compared to the Tu-144 (amounting to as much as 9 in supersonic cruise and up to 15 at subsonic speeds) and a more fuel-efficient powerplant with an SFC of 1.15 kg/kgp·hr in supersonic cruise. The maximum take-off weight was envisaged as 360 tons (793,650 lb), including a 30-ton (66,140-lb) payload; depending on the interior layout, the Tu-244 was to seat between 260 and 321 passengers. Cruising at 2,340 km/h (1,453 mph), the aircraft was to have a range of 8,000 km (4,970 miles).

In late 1976 the Soviet government passed a directive determining the Tu-244's main specifications and its course of development. In accordance with this document the SPS-2 programme was split into two stages, the first of which was to result in the creation of a relatively small SST having a take-off weight of 245-275 tons (540,120-606,260 lb), a wing area of 750 m² (8,064 sq ft) and four engines rated at 22,500-27,500 kgp (49,600-60,630 kgp). A larger SST was to be developed in the course of Stage Two.

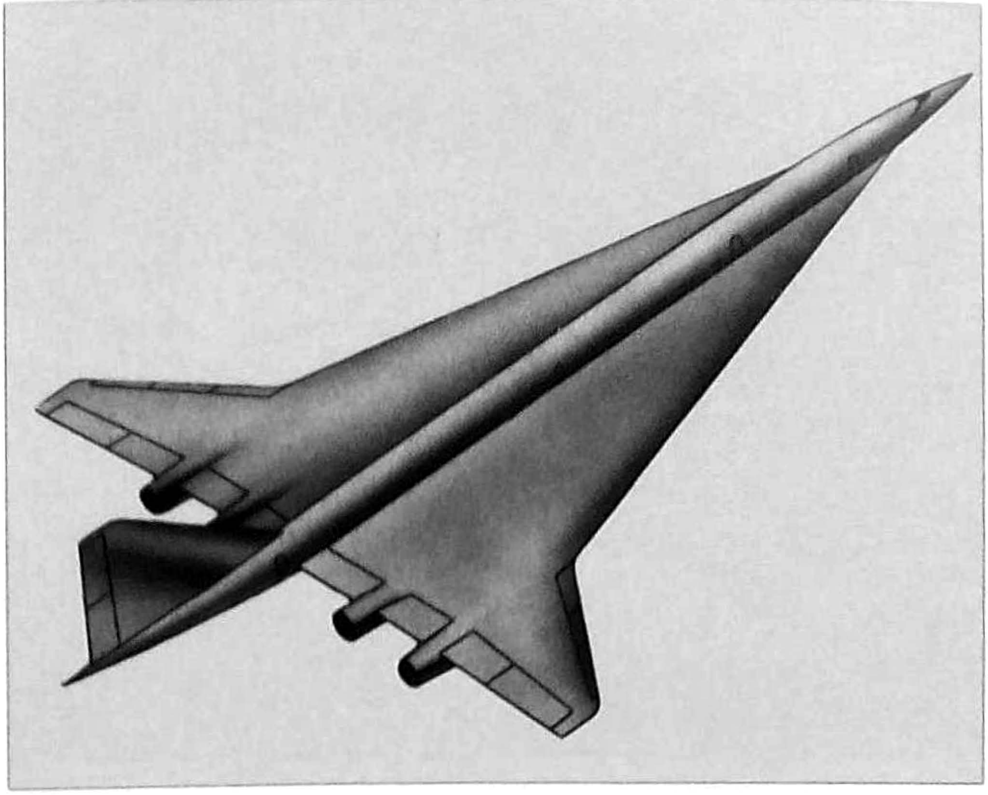
The technological complexity of the task and the skyrocketing development costs associated with advanced supersonic airliners compelled the leading aircraft manufacturers in the USA, Great Britain, France, Germany, Japan and Russia to pool their efforts and their expertise when developing second-generation SSTs. The result was the so-called Group of Eight, an association formed by the Boeing Commercial Airplane Group, McDonnell Douglas, British Aerospace, Aérospatiale, Deutsche Aerospace,



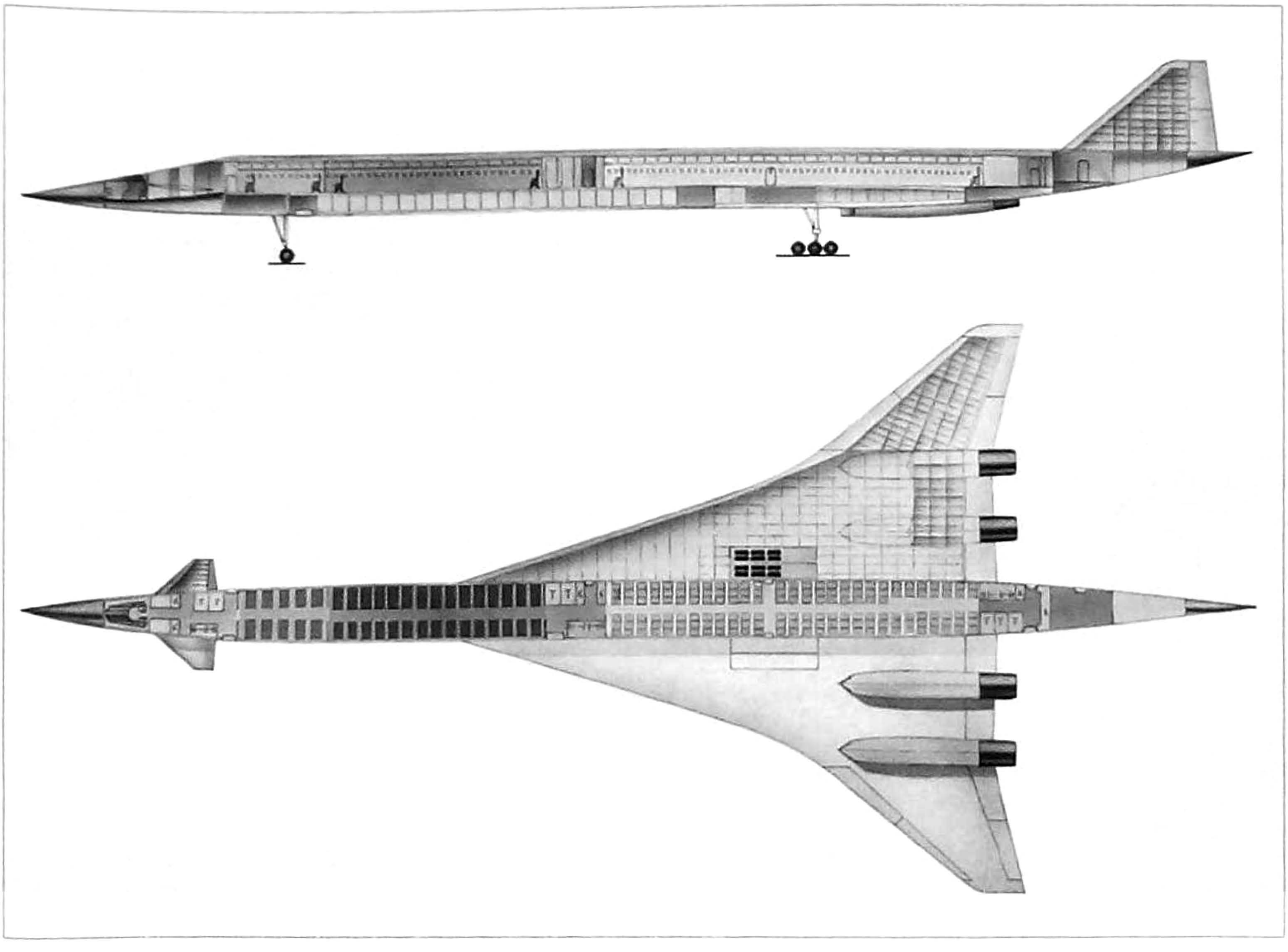
This artist's impression shows the latest configuration of the Tu-244 featuring two-dimensional air intakes with centrally mounted V-shaped intake ramps.

Alenia, the association of Japanese aerospace companies and ANTK Tupolev.

Falling back on its previous design studies under the SPS-2 programme, ANTK Tupolev now pursued the second-generation SST idea further as part of the Group of Eight, assisted by Russia's leading aerospace industry research centres (TsAGI, TsIAM, VIAM and LII). As a result, by the mid-1990s the design of Russia's prospective 21st-century supersonic airliner had virtually crystallised. In its ultimate configuration the Tu-244 retains the tailless-delta, cranked-wing layout but the powerplant now comprises four non-afterburning turbofans housed in widely spaced individual nacelles adhering to the wing underside; the TOW is increased to 320-350 tons (705,470-771,600 lb) and the seating capacity to 250-300, and the aircraft is to cruise at Mach 2.0-2.05. The airframe is to make large-scale use of composite structures. The type of engines to be used remains to be finalised; both variable-cycle engines (operating as turbofans for take-off/landing and as supersonic ramjets in cruise flight) and ordinary turbofans equipped with ejector-type nozzles to reduce the



Above: This drawing shows a late Tu-244 wing configuration with greatly enlarged LERXes and reduced sweepback on the outer wings featuring leading-edge flaps,



A cutaway drawing of another late project version of the Tu-244. Note the non-retractable cropped-delta canards, the kinked wing trailing edge and the 12-wheel main gear bogies retracting forward into the relatively thick inner wings. Interestingly, the aircraft appears to have a fixed-geometry nose.

The Tu-344 supersonic business jet has few competitors as the most unusual 'civilianisation' project. This model shows the passenger entry door and cabin windows ahead of the engine air intake.

acoustic signature on take-off and landing are under consideration. The chosen design and performance parameters are to make the Tu-244 a strong competitor to such long-haul subsonic widebodies as the Boeing 747 and the Airbus Industrie A310.

Despite the well advanced state of the design work, the Tu-244 remains a 'pie in the sky' project, and it will certainly be a long time before that pie is carved. Quite apart from the (alas) traditional financial factors, the world airline market is currently unprepared for a new SST that would take over from the recently withdrawn Concorde. The latter point is illustrated by the unhappy fate of Boeing's Sonic Cruiser (which, mind you, was not even supersonic but transonic) and, more recently, the considerable customer interest towards the subsonic but extra-large Airbus Industrie A380 'mega-jumbo'.

Tu-344 Supersonic Business Jet

Throughout the 1990s a certain interest has been displayed in a different class of SSTs – executive aircraft seating up to 20 passengers and known as supersonic business jets (SSBJs). The Sukhoi OKB, a well-known 'fighter maker', was the first Russian company to undertake development of such specialised aircraft.

The Tupolev PLC joined the game in the late 1990s. Being well aware of the financial hurdles and trying to overcome them, the company opted for a rather unusual approach that reduced the development costs dramatically. Quite simply, the projected SSBJ (designated Tu-344) was a straightforward adaptation of the Tu-22M3 multi-mode long-range bomber. The latter's airframe (including the variable-geometry wings) and powerplant remained unchanged but all military equipment was removed and a VIP cabin featuring all required amenities and facilities replaced the weapons bay.

However, the Tu-344 was doomed from the outset, as it had inherent major weaknesses. For one thing, the Kuznetsov NK-25 afterburning turbofan was a military engine and had manners to match, with an appallingly 'dirty' efflux having a high nitrous oxide content. In today's environmentally conscious world, not only would the operator of such a 'dirty' aircraft have to pay fines but his business reputation might suffer. Secondly, because of the lateral air intakes and their long inlet ducts the Tu-344's cabin would be decidedly claustrophobic, with only a couple of windows on each side immediately ahead of the intakes. Finally, the ex-bomber with its menacing looks and air of brute force lacked the style of modern business jets.

There was even a rather wicked joke that the Tu-22M3's tail barbette mounting a twin-barrel 23-mm Gryazev/Shipoonov cannon might justifiably be retained on the Tu-344 in case the businessman's competitors should obtain fighters for the purpose of shooting him down, taking contract killings up to a new level - literally! And what about ejection seats for the VIPs?

Tu-444 Supersonic Business Jet

As a well-known saying goes, time is money. This magic formula works both ways: 'use your time rationally to do business and make money' and 'spend money to buy yourself some time' (that is, invest in means of rapid conveyance), and it became especially significant in the 1990s when global integration came on the agenda. In a situation when the business trips of high-ranking executives become increasingly longer and more frequent, with ever-greater distances to be covered, the need to dramatically reduce the time needed to get from A to B becomes vital. To a certain degree this need is met by business jets, the modern ones matching the speed and range of the latest long-haul airliners. Also, the independence from airline schedules that they give and their ability to operate from runways no more than 2,000 m (6,560 ft) long makes biz-jets just about the only travel alternative for the serious businessman. Still, since many trips involve ocean crossings rather than city-hopping, the need to reduce the travel time drastically is still there.

That said, the advent of SSBJs appears to be inevitable. The question is, on what technological level and in what form they will materialise? The research on second-generation SSTs performed in various countries, both nationally and jointly, provides some clues.

Despite the progress made in combat aircraft and airliner technology, and despite the large amount of R&D work already done on the SST-2, a large supersonic airliner will not be economically viable in the foreseeable future because of the extremely stringent ecological standards which today's airliners have to meet. Quite simply, the cost of incorporat-

ing the measures ensuring compliance with the said requirements would prove prohibitive. Hence a small SSBJ would appear to be the most likely application for the know-how accumulated under the SST-2 programme at this stage. Therefore the Tupolev OKB started work on such an aircraft designated Tu-444. First of all, such an aircraft is considerably cheaper to design and build than a full-size supersonic airliner; secondly, it is far easier to adapt to the stringent environmental protection requirements by incorporating appropriate design features.

According to notable aircraft industry and air transport experts, the potential world market for supersonic business jets amounts to 400-700 aircraft, provided that the operating costs are no more than 20% higher than those of the subsonic business jets in the same class. The SSBJ's main advantage over its subsonic counterparts with intercontinental range is the ability to take its passengers across the ocean and bring them back home within 24 hours, maximising the use of their valuable time.

Unlike the Tu-344, the Tu-444 is a 'clean sheet of paper' design, although it (inevitably) draws heavily on the features of the Tu-144 and Tu-244. The design of the Tu-444 was influenced by the following factors:

• Analysis of possible low-density air routes linking the world's 75 key cities (this analysis was part of the Tu-244's R&D effort) showed that creating an ultra-long-range SSBJ capable of flying 11,000-12,000 km (6,830-7,450 miles) non-stop is inexpedient. Businessmen rarely travel such long distances, and the advantage of long range would not justify the aircraft's much higher price. The most rational range for an SSBJ was determined as 7,000-7,500 km (4,350-4,660 miles); should the need arise, ultra-long-range flights could be made with one refuelling stop.

• Operational experience with the Tu-144 and the Tu-160 strategic missile strike aircraft showed that it made sense to restrict the cruising speed to Mach 2.0 and restrict the service ceiling in order to maximise the aircraft's service life.

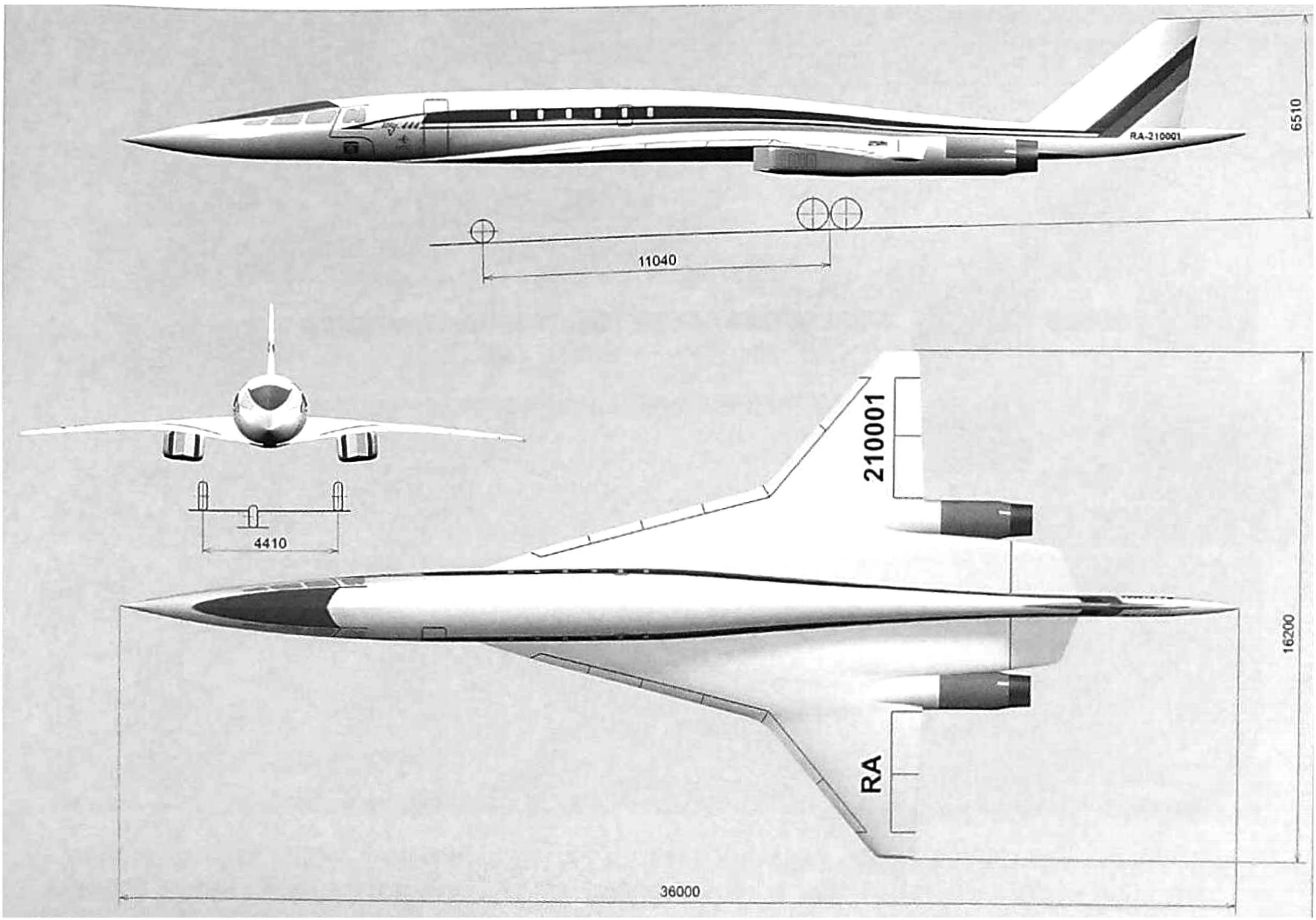
• Proceeding from the design experience gained with the Tu-244, the optimum wing loading was determined as 320 kg/m² (65.6 lb/sq ft).

• Operational experience with such widely known biz-jets as the Cessna Citation III and Citation X, British Aerospace (now Raytheon) 125, Dassault Falcon 900, Canadair (now Bombardier) Challenger, Bombardier Global Express and Gulfstream Aerospace GII, GIII, GIV and GV shows that on average they carry three to six passengers on each flight, regardless of their differing seating capacity.

• Finally, analysis of the world's airfield network indicates that an SSBJ should be capable of operating from runways no more than 1,800 m (5,900 ft) long.

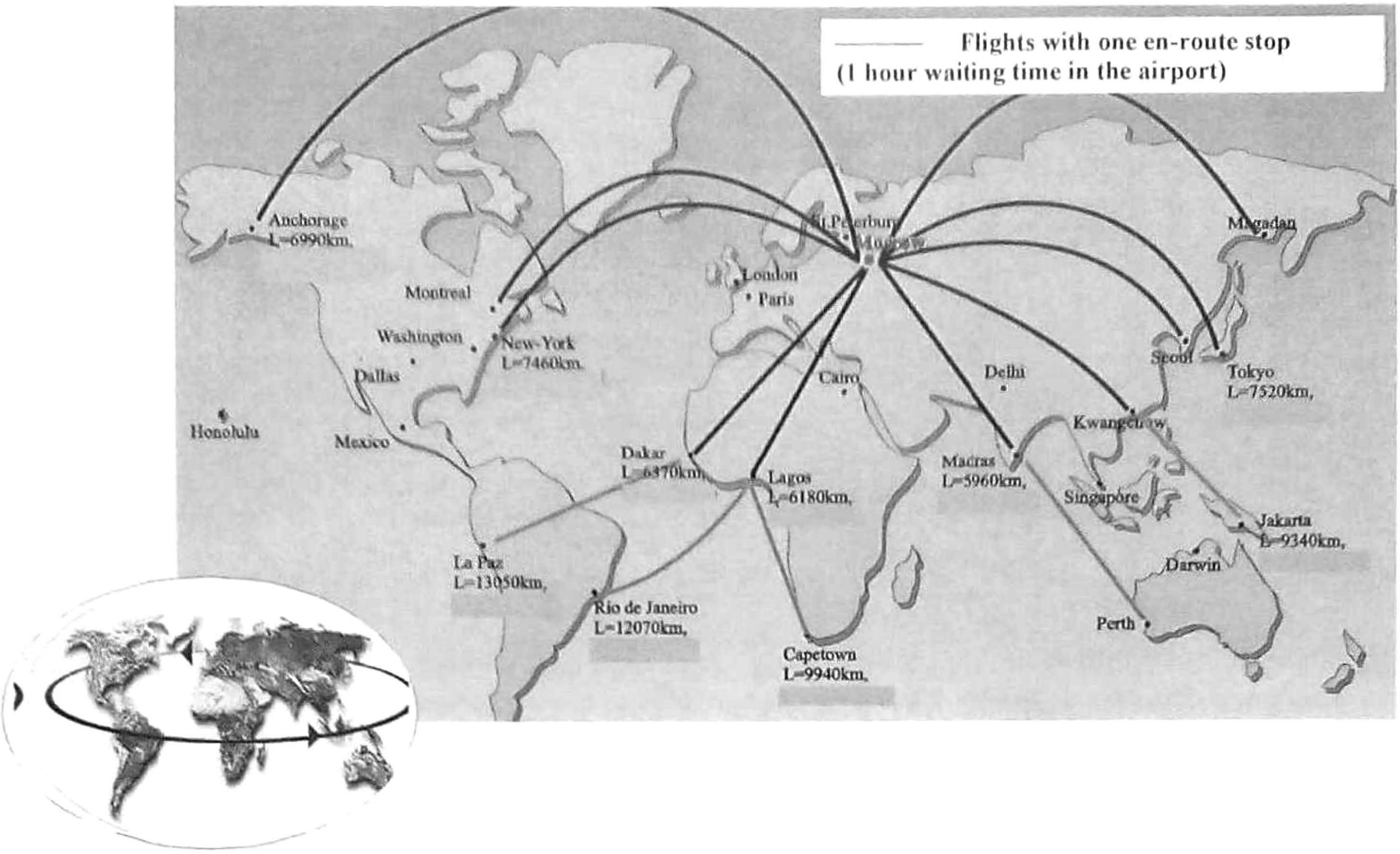
Building on the experience gained with the Tu-144, Tu-144LL, Tu-22M3 and Tu-160, as well as on the know-how evolved in the course of the Tu-244 programme, the design staff of ANTK Tupolev set to work. The end result was the Tu-444 supersonic business jet which, in its finalised project form, has the specifications stated in the table on page 105.

It should be noted that, despite the wealth of theoretical and practical experience with long-range supersonic jets and the well-developed manufacturing facilities for same, a number of tough technical problems have to be resolved before a workable and highly efficient SSBJ can materialise. Many of them are unique to this class of aircraft.

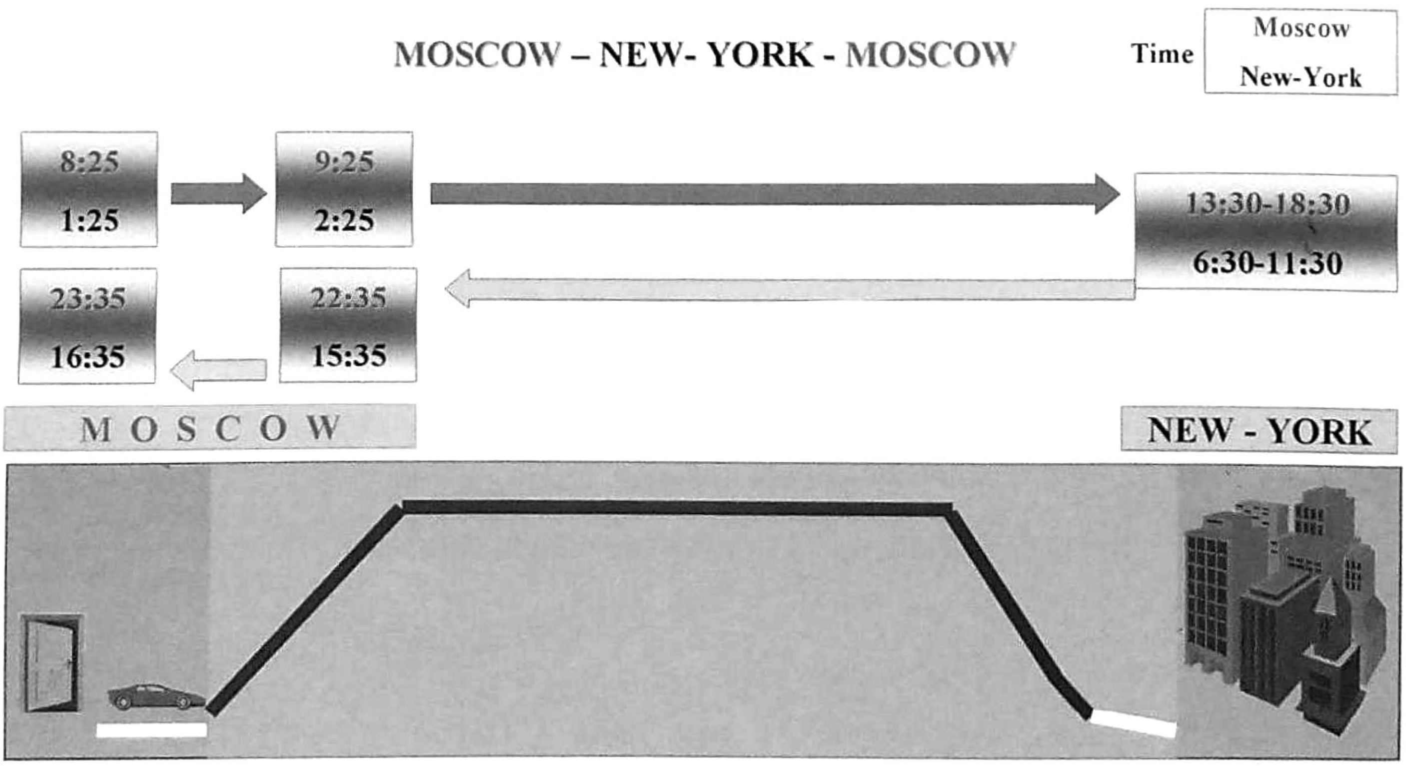


A three-view of the Tu-444. Note the wing shape similar to that of the Tu-244 in its final form, the offset nosewheel, the leading-edge flaps, the position of the engines relative to the wings, and the longitudinal trim flaps.

POSSIBLE FLIGHT ROUTES AND DESTINATIONS



A ROUND TRIP IN ONE DAY



Tu-444 ALLOWS A BUSINESSMAN TO LEAVE HIS OFFICE IN MOSCOW AT 8.30 IN THE MORNING AND TO BE BACK IN MOSCOW AT 23.35 ON THE SAME DAY, AFTER HAVING HAD A 5 HOUR BUSINESS MEETING IN NEW YORK

The main challenge associated with the Tu-444 project is the need to reconcile the required range (7,000-7,500 km) with good field performance (a required runway length of no more than 1,800 m) and low noise pollution, especially alongside the runway (the aircraft has to be ICAO Chapter 16/Stage III compliant, with the ability to meet Stage IV requirements when they come into effect). The range target is all the harder to meet because the Tu-444 is about 50% smaller overall and has an approximately six times lower all-up weight than the SST-2 (Tu-244), whereas the share of the fuselage cross-section in the total frontal area is greater. This makes it harder to attain the specified maximum cruise lift/drag ratio of 8 and the specified fuel load/AUW ratio of 0.51-0.515.

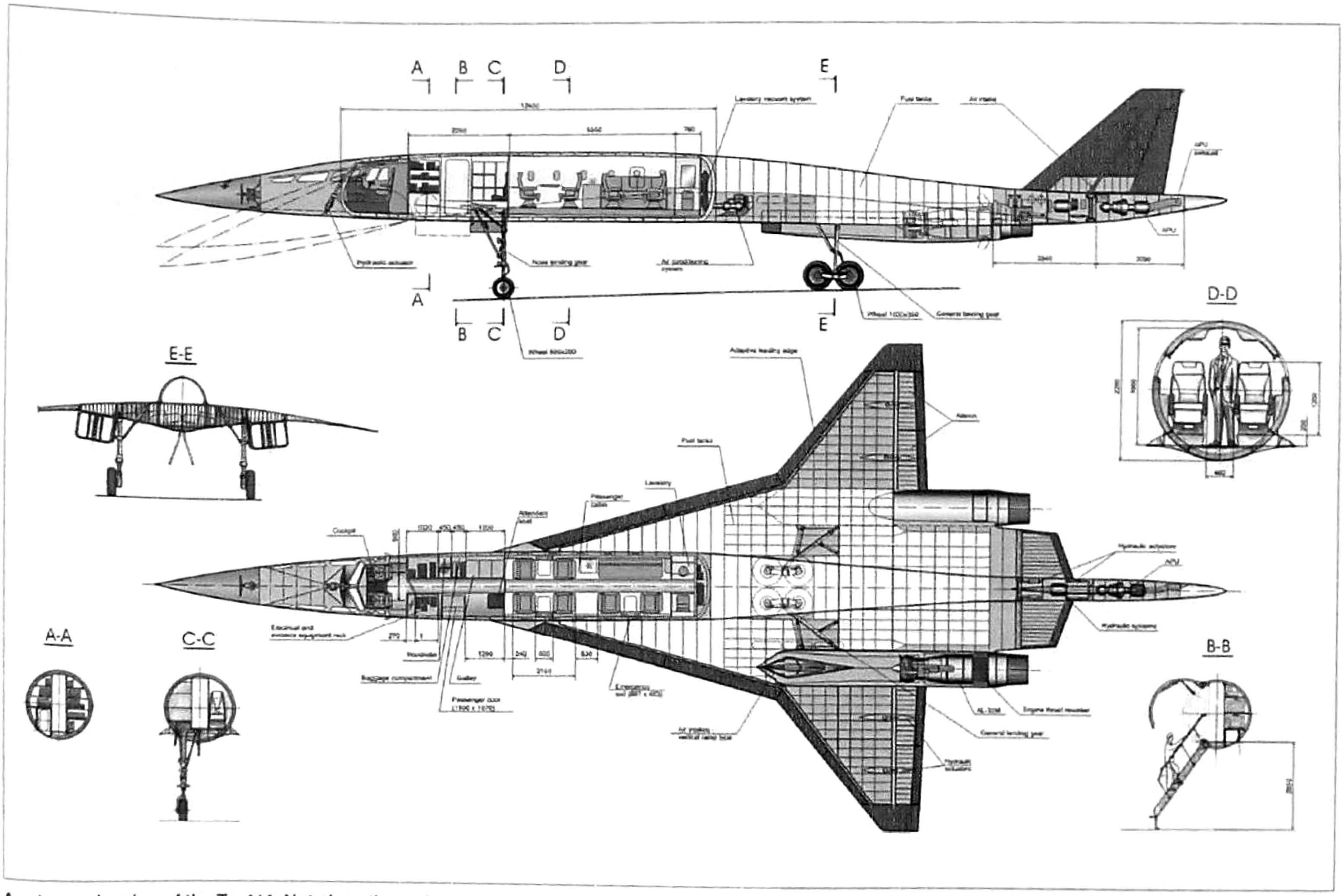
To solve this problem, the structural weight has to be reduced so that the fuel load/AUW ratio improves. This requires the use of advanced structural materials (including composites) and careful optimisation of the airframe's load-bearing structure to ensure the specified service life (fatigue resistance), the highest possible flutter onset speed and minimise the reduction of control authority caused by aeroelasticity. The SSBJ's climb trajectory also needs to be optimised; the Tu-144's climb trajectory was not the most efficient one.

Specifications of the Tu-444

Crew	3 (two pilots and one flight attendant)
Passengers (normal/maximum)	6 (10)
Length overall	36 m (118 ft $1\frac{21}{64}$ in)
Height on ground	6.51 m (21 ft $4\frac{19}{64}$ in)
Wing span	16.2 m (53 ft $1\frac{51}{64}$ in)
Wing area	136 m² (1,462 sq ft)
Powerplant	2 x Lyul'ka AL-32M
Take-off thrust at sea level	2 x 9,700 kgp (21,380 lbst)
Maximum take-off weight	41,000 kg (90,390 lb)
Empty weight	19,300 kg (42,550 lb)
Maximum fuel load	20,500 kg (45,190 lb)
Normal/maximum payload	600/1,000 kg (1,320/2,204 lb)
Cruising speed:	
supersonic (Mach 2.0)	2,125 km/h (1,320 mph)
subsonic (Mach 0.95)	1,050 km/h (652 mph)
Effective range with NBAA IFR fuel reserves	7,500 km (4,660 miles)
Required runway length	1,830 m (6,000 ft)

Paring excess weight off the Tu-444 concerns its systems and equipment, too; thus, greater reliability of the main systems, not multiple redundancy, is the way to go. To illustrate the point, the Tu-144 has a quadruply redundant hydraulic system (four independent systems), while the Concorde's hydraulics have a redundancy of 2.5 ('two and a half hydraulic systems').

In practice, Chapter 16/Stage III (Stage IV) compliance combines with a runway length of 1,800 m means that the Tu-444 has to have an ambient noise level at least 14-18 EPNdB lower than the Tu-144 at any given reference point. This necessitates development and refinement of a totally new hushkitting system, optimisation of the wing high-lift devices, development of noise abatement procedures



A cutaway drawing of the Tu-444. Note how the main gear struts swing forward during retraction and how their bogies align themselves with the fuselage axis.

(by throttling back the engines in a certain order) and piloting procedures for the take-off and landing stages of the flight.

The short-field requirement coupled with the powerplant comprising two (rather than four) engines means that the SSBJ's approach and landing speed needs to be about 100 km/h (62 mph) lower than the Tu-144's and Tu-244's. In practice this means that the Tu-444 will use a 'fighter-style' take-off and landing technique involving higher angles of attack and make use of powerful high-lift devices and effective flight controls.

The preliminary design stage made it patently clear that full-scale development of the Tu-444 would have to start with the construction and testing of a demonstrator aircraft. This aircraft would allow the novel design features to be verified and reveal any hidden operational peculiarities that an SSBJ might have; it would also serve for measuring pressures, structural stresses and airframe skin temperatures in every single flight, obviating the need for a complex and costly thermal/fatigue life test rig. The demonstrator's test flights are vital for developing and perfecting the optimum take-off and landing profiles and optimising the flight level and speed with regard to the underlying terrain and the weather for the purpose of minimising the sonic boom.

In order to cut development costs the demonstrator may differ from the future production-standard aircraft in utilising slightly different structural materials and having a simplified airframe design and avionics/equipment suite. For instance, as distinct from the production Tu-444 which is to have a 'solid' forward fuselage structure with a fixed nosecone, the demonstrator will feature a drooping nose visor and its actuator borrowed straight from the Tu-144; the flightdeck design and other features will be taken from the same aircraft. Nevertheless, the demonstrator will be built to meet the requirements of the Russian AP-25, US FAR-25 and European JAR-25 airworthiness regulations, ETOPS-180, HIRE and HPMD procedures and other regulatory documents concerning flight safety. In order to simplify production and reduce costs the aircraft is to have maximum commonality with aircraft types currently in production and service as regards systems and equipment.

Given the abbreviated ground test cycle, the demonstrator shall be fitted with a comprehensive test instrumentation suite. This will allow the flight test programme to progress steadily, furnishing the required amount of test data for the assured development of the production-standard SSBJ and its subsequent tests and certification.

Due to the design differences mentioned earlier the demonstrator will not be able to match the project performance of the production SSBJ. Yet its test programme will provide proof positive that the desired flight performance and operating economics can be obtained; it will also provide the basis for tooling up for series production. The full-scale development and production entry of the Tu-444 will undoubtedly call for a lot of engineering and organisational effort – and large investments. This is where the demonstrator comes into the picture in another capacity: it will help to work out the interaction between the various partners and subcontractors in the programme. Also, the demonstrator will have yet another role; we started off with one universal truth and we'll finish with another: 'no publicity – no prosperity'. That is, the demonstrator will serve to attract customer interest at various air events, promoting the introduction of SSBJs.

Structural Details of the Tu-444

The Tu-444 utilises the tailless-delta layout. The sharply area-ruled fuselage is a semi-monocoque stressed-skin structure with a high fineness ratio; the fuselage has a basically circular cross-section. Structurally the fuselage is divided into three sections. The pressurised forward fuselage accommodates the two-man flightdeck, with avionics bays and the nosewheel well aft of it; the fuselage nose incorporates a conical glassfibre radome tipped with a pitot. Further aft is the entry vestibule with an upward-opening rectangular entry door (equipped with integral airstairs) on the port side, a galley and a coat closet, followed by a cabin and a toilet. The cabin can be configured for six or ten passengers. The centre fuselage is a huge integral fuel tank with an air conditioning system bay at the bottom. The sharply tapered unpressurised rear fuselage carries the tail unit. It accommodates the auxiliary power unit, hydraulic and electric system components.

The cantilever low-set wings of low aspect ratio have a compound-delta planform with large LERXes and a cranked leading edge. The wings feature variable spanwise and chordwise camber and compound deformation of the wing centre section. The thickness/chord ratio varies from 2.5% to 3.5%.

The LERXes are 'wet', housing integral fuel tanks divided into several sections. The wing centre section carries the engine nacelles adhering directly to the undersurface, with the air intakes located under the LERXes; part of the space between the nacelles is occupied by the mainwheel wells.

The entire wing leading edge is occupied by multi-section adaptable leading-edge flaps increasing the lift/drag ratio in various flight modes; these may be locked neutral on the demonstrator aircraft. The trailing edge features elevons (drooping to operate in flap mode for take-off and landing) outboard of the engines and large balance flaps inboard; the balance flaps extend far beyond the outer wing trailing edge and serve for longitudinal trim. The use of retractable shoulder-mounted canard foreplanes mounted aft of the flightdeck, as on the Tu-144 (*izdeliye* 004), is being considered.

The tail unit consists of only a large all-movable fin serving for directional control.

The hydraulically retractable tricycle landing gear comprises a forward-retracting single-wheel nose unit (offset to starboard to maximise the use of internal space) and inward/forward-retracting twin-wheel main units, each of which has a bogie with two wheels in tandem.

The powerplant of the production Tu-444 is to comprise two Lyul'ka-Saturn non-afterburning turbofans developed specially for this aircraft. The AL-32M is based on the AL-31F afterburning turbofan powering the Sukhoi Su-27 *et seq* fighter family, incorporating some design features of the AL-41F-1 advanced afterburning turbofan developed for fifth-generation fighters and featuring a cascade-type thrust reverser. The demonstrator aircraft, however, will be fitted with afterburning turbofans for the purpose of exploring the limits of the flight envelope.

The engines are housed in nacelles adhering to the wing undersurface, breathing through two-dimensional supersonic air intakes; these are scaled-down versions of the paired intakes used on the Tu-160, featuring a V-shape when seen from below and incorporating centrally-mounted vertical airflow control ramps opening out like bellows. The engines proper are mounted aft of the wing torsion box and inclined slightly nose-down, so that the rear fuselage and fin shield the nozzle of the far engine from the 'casual listener' during the take-off run, reducing the perceptible noise. An APU is installed in the rear fuselage for self-contained engine starting, AC/DC ground power supply and air conditioning.

The Tu-444 features a multi-channel fly-by-wire (FBW) control system. The aircraft is designed to be statically unstable in the pitch and roll channels in order to maximise the lift/drag ratio and improve field performance.

The avionics suite may utilise an open architecture allowing its capabilities to be expanded by adding new modules on the way from the demonstrator to the production aircraft.

The aircraft will feature a full set of life support and rescue equipment for the crew and passengers (an air conditioning and pressurisation system, an oxygen system, life rafts and so on).

Tu-144 in Uniform?

Projected Military Versions

Since the project of the Tu-144 supersonic airliner offering outstanding flight performance was making steady progress, the Tupolev OKB began contemplating possible military uses for this aircraft. The Soviet military, too, evinced an interest in the Tu-144 as a possible weapons platform for various missions. Over the years, while the Tu-144 was in the throes of its gestation period and then enjoying its brief production life, the Tupolev OKB had several military versions of the Tu-144 on the drawing boards.

Liquid Hydrogen-Fuelled Supersonic Reconnaissance Aircraft

Back in 1967, when the Tu-144 powered by NK-144 afterburning turbofans did not even exist in hardware form, the OKB developed a spyplane version of the airliner. This, in itself, would be nothing out of the ordinary, had it not been for one thing – the aircraft's engines were to run on liquid hydrogen (LH_2)! The project got as far as the ADP review stage but was scrapped when the Ministry of Defence refused to finance it.

In passing, it should be noted that there were several projected versions of the Tu-144 as an airliner utilising cryogenic fuels – LH_2 and liquefied natural gas (LNG). The cryogenic tanks were to be housed in the fuselage, with an attendant reduction in the seating capacity and payload. Estimates showed that, while the conversion would lead to a 10% reduction in the cruise lift/drag ratio, a hydrogen-fuelled version of the Tu-144 would have a 25-30% lower take-off weight. Of particular importance was the fact that the fuel burn of the cryogenic version would be reduced by more than 65% over the more conventional version thanks to the higher calorific value of the cryogenic fuels.

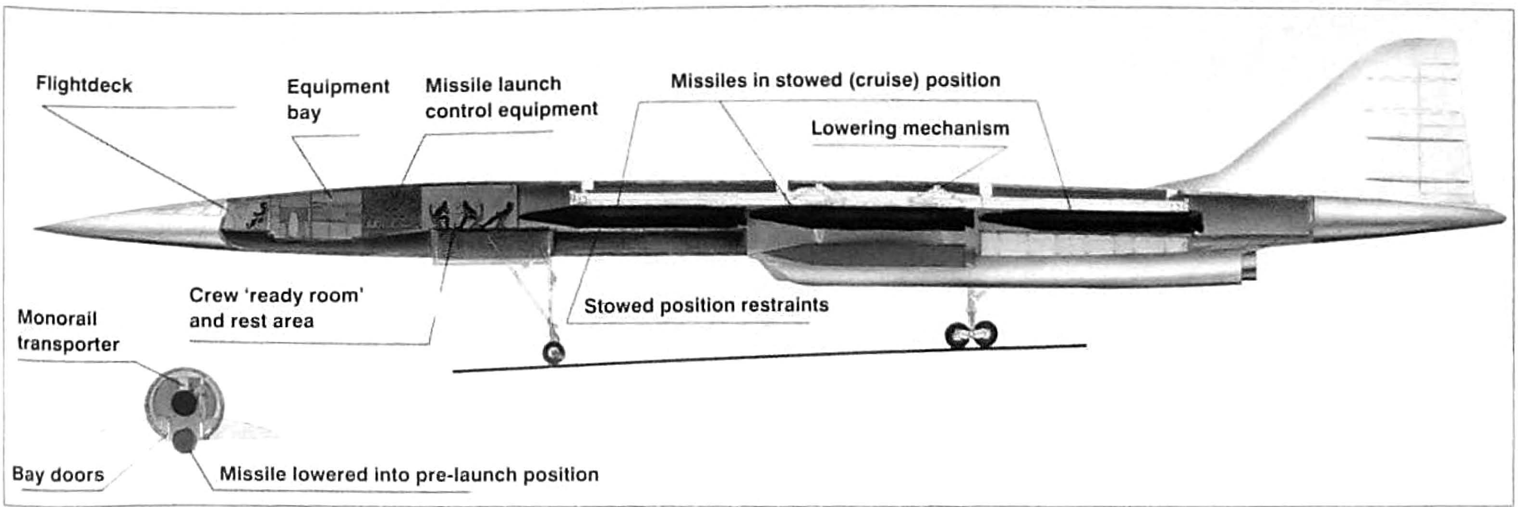
Tu-144R Missile Strike System

In the early 1970s the production-standard Tu-144 *sans suffixe* with NK-144A engines served as the basis for a projected aerial missile strike system designated Tu-144R (*raketo**nosets*** – missile carrier). The aircraft was to carry up to three long-range air-launched intercontinental ballistic missiles with solid-propellant rocket motors in a fuselage weapons bay between the engine nacelles. The launch was to take place over Soviet territory, the aircraft accelerating to 2,300-2,500 km/h (1,428-1,552 mph) before releasing the missile. A number of Tu-144Rs were to stand on quick-reaction alert at airbases around the country, ready to mount a missile attack at any time; to minimise the reaction time the crew would sit in a special cabin or 'ready room' in the aircraft, waiting for the 'action stations' command and ready to 'take her up' within a few minutes.

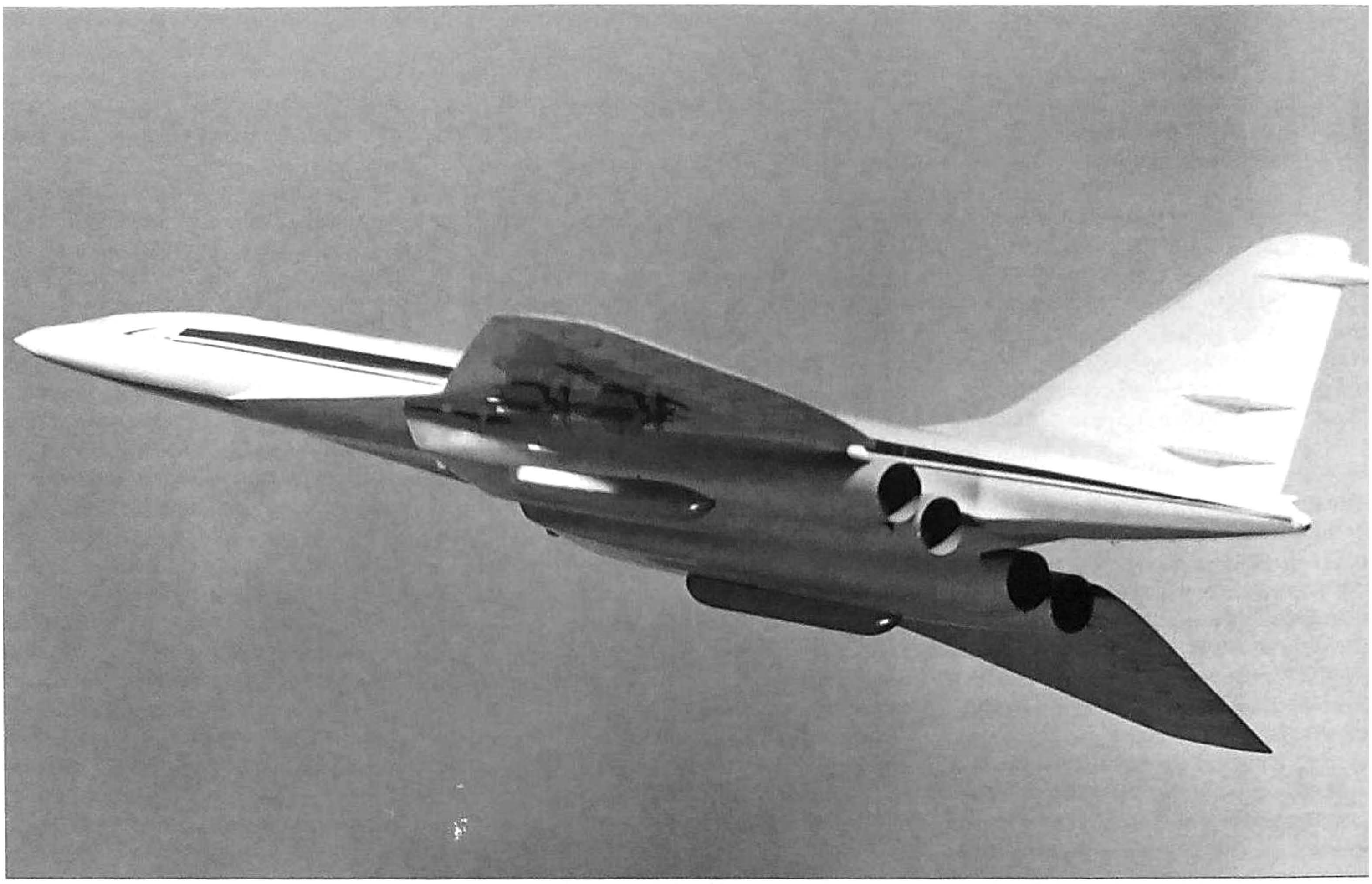
This combination of round-the-clock readiness and the missile platform's high supersonic speed significantly improved the air-launched missile system's reaction time, which matched that of ground- and sea-launched ballistic missiles, and significantly reduced the system's deployment costs due to the relative cheapness of its ground components. Such a two-stage system made it possible to add the relatively short supersonic range of the aircraft to the missile's long range. The missile platform's high mobility and the fact that the launch was to take place over 'friendly' territory where the aircraft was immune against enemy air defences improved the system's survivability. Also, unlike ground-launched ICBMs, in the event the alarm turned out to be false the attack could be aborted within the first hour after the order to attack had been given.

The flight performance of the Tu-144R was similar to that of the airliner version. The maximum launch radius was set at 2,500 km (1,552 miles) from the base, which gave the missile system an overall range of 7,000-9,000 km (4,350-5,590 miles).

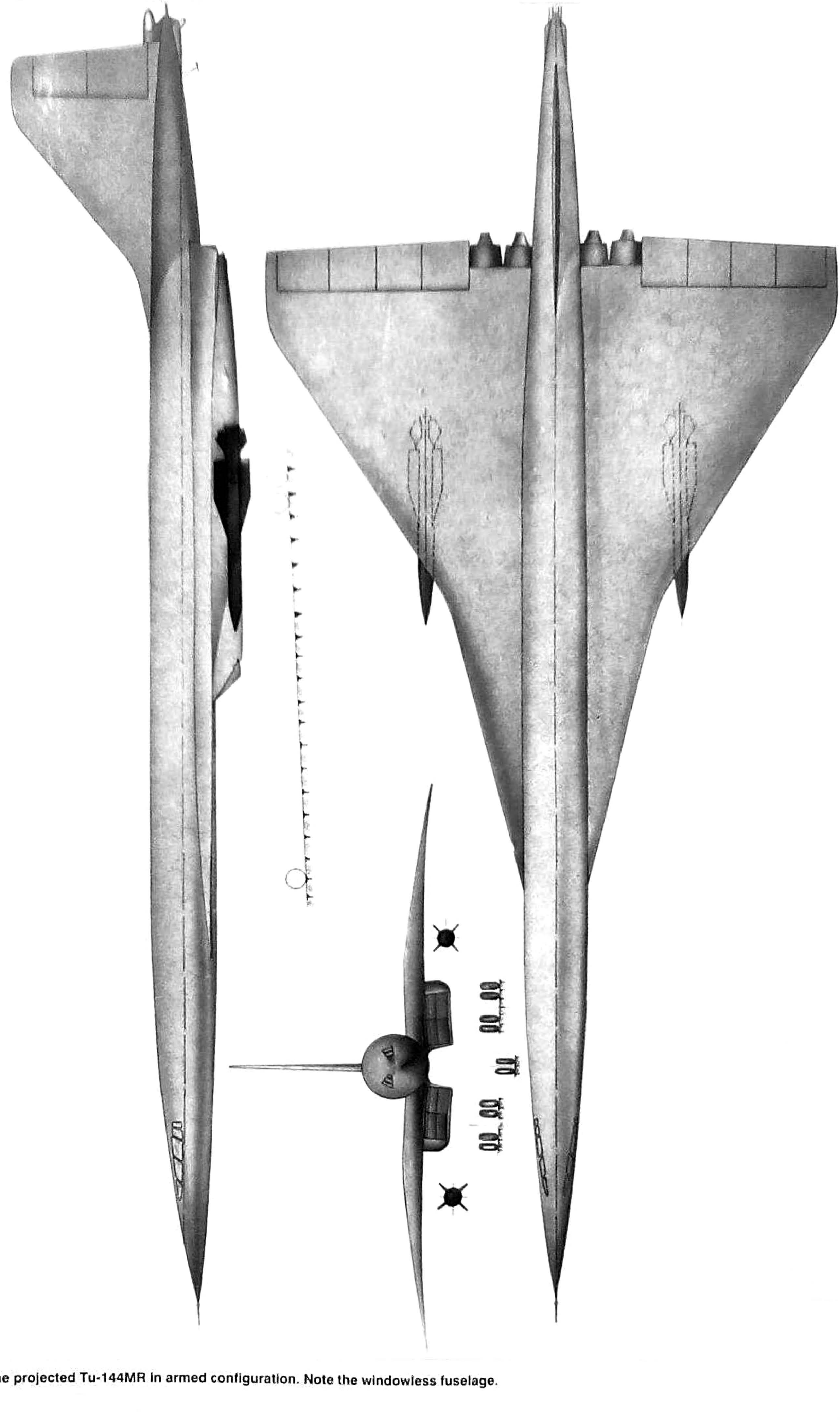
Later, a similar air-launched missile system based on the longer-range Tu-144D was devised. The aircraft was to have an increased fuel supply as compared to the airliner version and be armed with much smaller and lighter missiles having a range of 3,000-5,000 km (1,860-3,100 miles). In order to save fuel the flight to the launch point would mostly take place in subsonic cruise mode, the aircraft accelerating to supersonic speed immediately before the launch. Depending on the warload, the system's operational range would be 9,000-11,000 km (5,590-6,830 miles) with one missile and a flight range of some 6,000 km (3,730 miles); 8,500-10,000 km (5,280-6,210 miles) with two missiles and



A cutaway drawing of the projected Tu-144R missile carrier showing how the three air-launched ballistic missiles were to be stowed.



Above and below: A model of the Tu-144PP interceptor/ECM aircraft, showing the ventral jammer pods, the fin-mounted ECM antenna pod and the long-range air-to-air missiles.



A three-view of the projected Tu-144MR in armed configuration. Note the windowless fuselage.

a flight range of some 4,500 km (2,795 miles); and 8,000-9,500 km (4,970-5,900 miles) with three missiles and a flight range of some 3,500 km (2,170 miles).

Other missile strike versions of the Tu-144 which did not proceed past the preliminary design stage included versions armed with long-range air-launched cruise missiles similar to the Kh-55 carried by the Tu-95MS and the Tu-160. Interestingly, the programme also included studies of a powerplant in which the engines ran on kerosene while their afterburners used LH_2; such an installation, based on the NK-144A, passed bench tests.

DP-2 Long-Range Heavy Interceptor

In the late 1970s the OKB contemplated a heavy interceptor derivative of the Tu-144D designated DP-2 (***dahl'***niy pere***khvaht***chik – long-range interceptor). Actually it was more than just an interceptor; its mission was to escort 'friendly' strike aircraft on long-range missions, protecting them from enemy fighters, provide air defence of key areas within a large radius from its base and disrupt the enemy's air supply routes, seeking and destroying enemy transport aircraft.

Tu-144PP Long-Range Heavy Interceptor/ECM Aircraft

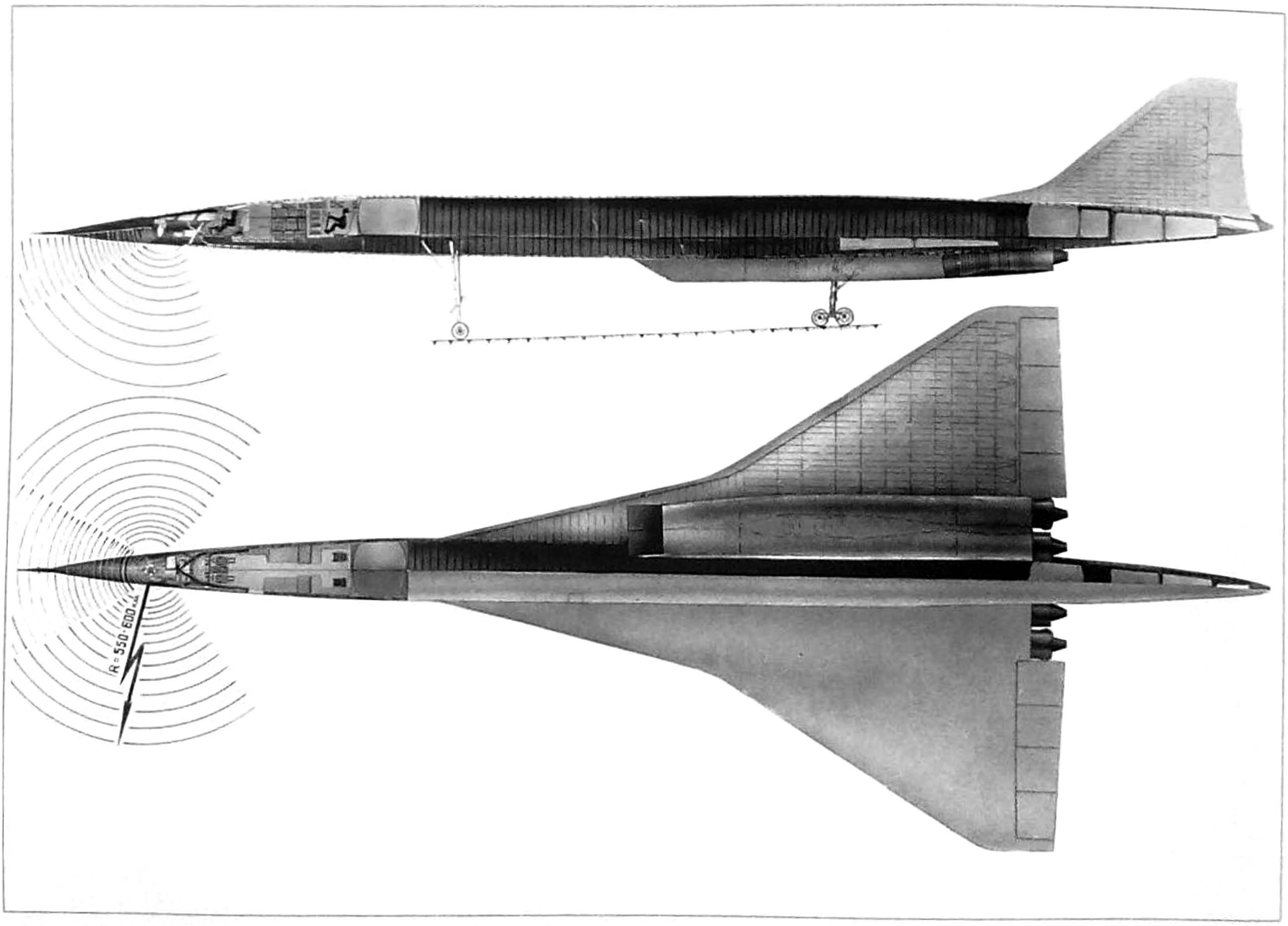
The DP-2 project later evolved into a multi-role aircraft designated Tu-144PP (*postanov-shchik pomekh*). As the suffix letters indicate, it had an additional role as an electronic countermeasures (ECM) aircraft providing ECM cover for 'friendly' strike aircraft formations and facilitating their task of penetrating the enemy's air defences.

Tu-144PR Long-Range Reconnaissance/ECM Aircraft

In 1980 the Tupolev OKB started some project studies on a reconnaissance/ECM derivative of the Tu-144D to be designated Tu-144PR (*ostanovshchik [pomekh]/razvedchik*). The aircraft was intended for theatre-strategic reconnaissance and suppression of enemy air defence radars. The Tu-144PR was conceived as a multi-role aircraft capable of operating in the interests of the Long-Range Aviation (DA – ***Dahl'****nyaya avi****ah****tsiya*, the strategic strike force) and the Air Defence Force (PVO – ***Pro****tivovoz****doosh****naya obo****ro****na*) by reconnoitring air targets and guiding other interceptors to them or providing target data for surface-to-air missile systems. The aircraft was to have defensive armament and a defensive ECM suite.

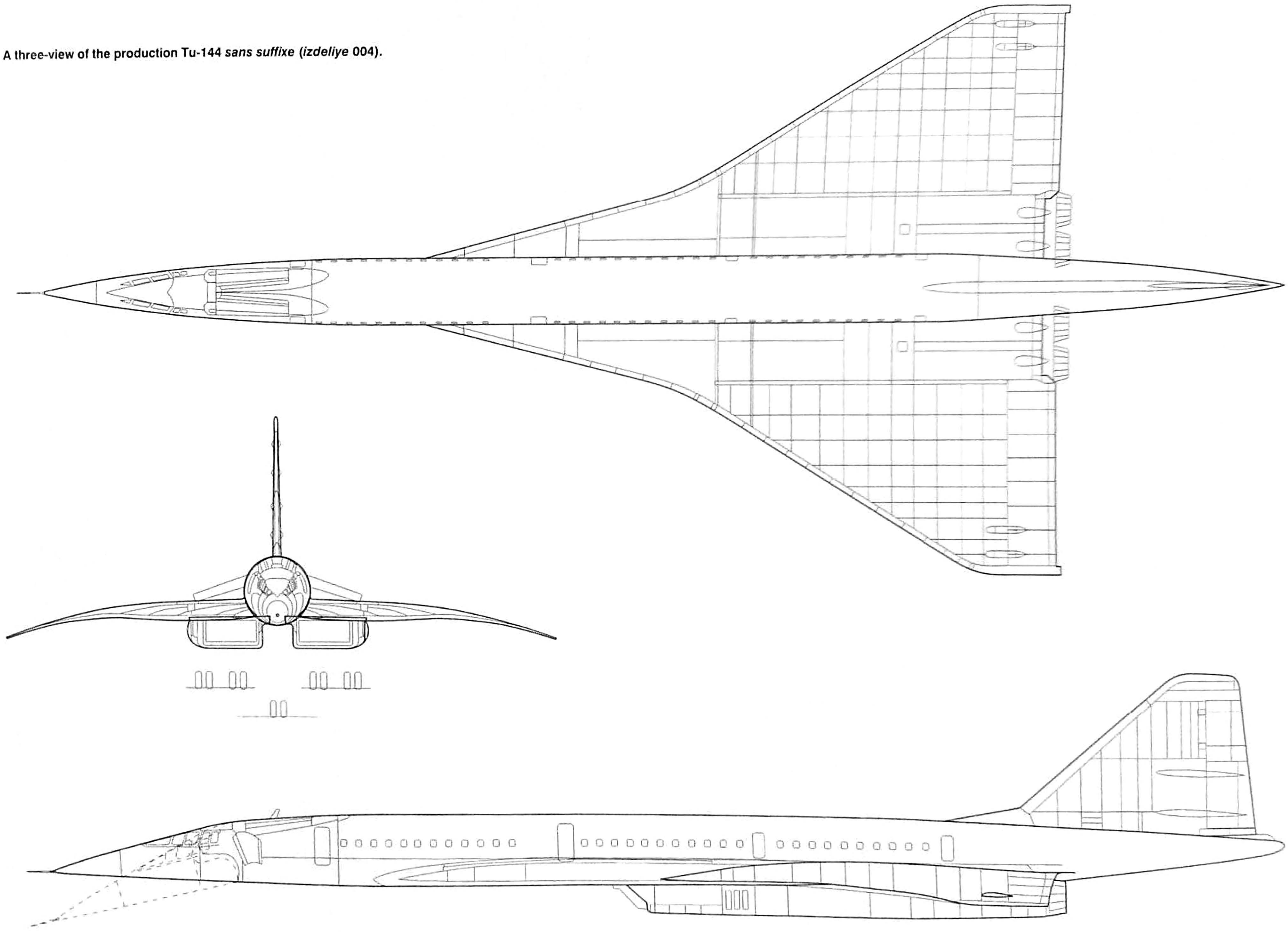
Tu-144MR Long-Range Maritime Reconnaissance/Strike Aircraft

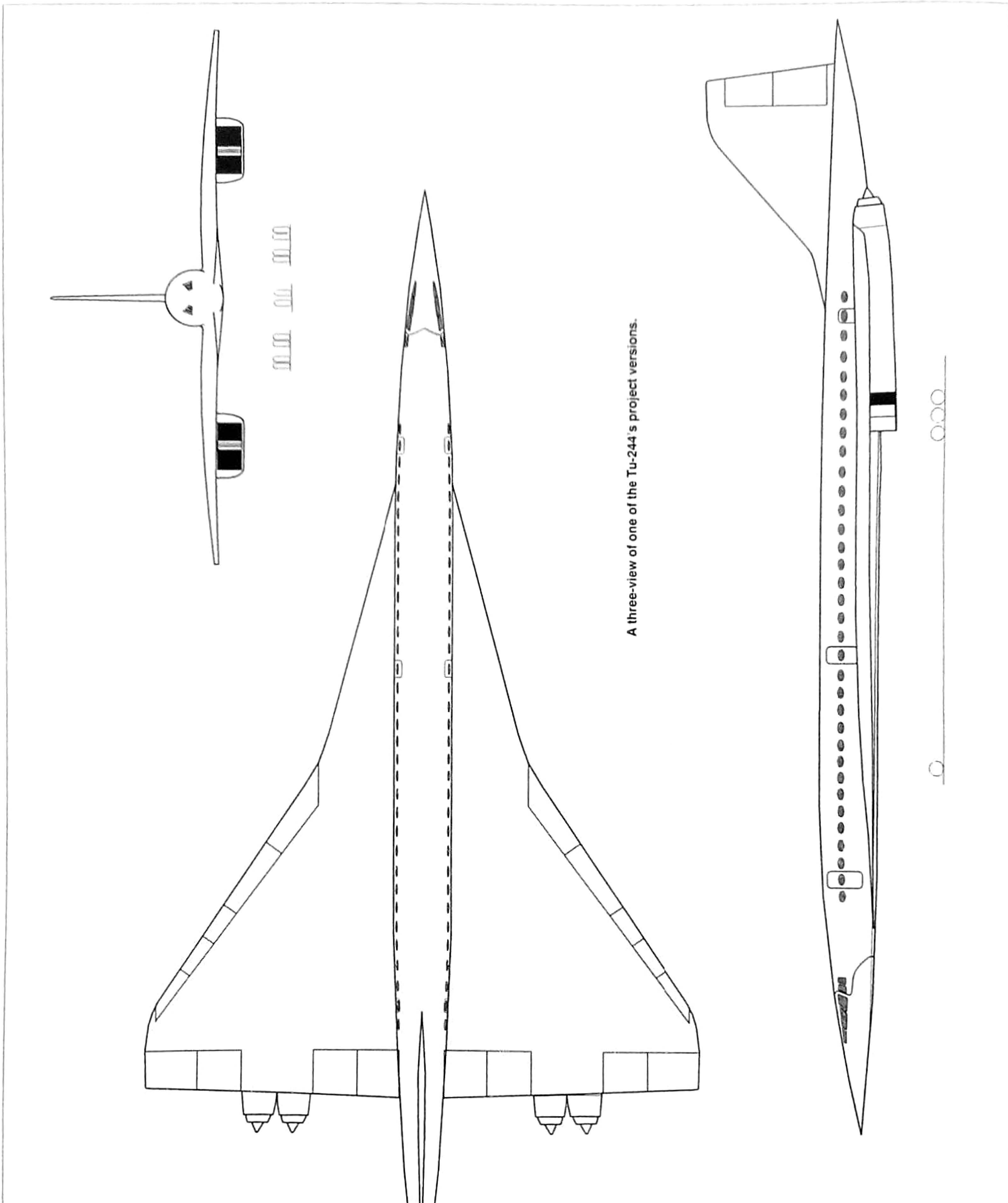
One of the last attempts to 'sell' the Tu-144 to the military was a project for a long-range reconnaissance aircraft for the Soviet Naval Air Arm (AVMF – *Aviahtsiya voyenno-morskovo flota*). Designated Tu-144MR (*morskoy razvedchik*), it was likewise based on the Tu-144D and intended for providing target information to the Navy's offensive components (surface ships and submarines) on sea and oceanic theatres of operations. To expand the Tu-144MR's capabilities, the OKB suggested developing and fielding a reconnaissance/ strike version armed with two Kh-45 air-to-surface missiles alongside the pure reconnaissance variant. The latter was to have a range of 10,000 km (6,210 miles), a top speed of 2,500 km/h (1,552 mph) and a typical flight altitude of 20,000 m (65,620 ft); the take-off weight was specified as 185 tons (407,850 lb), which was nearly 10% less than that of the passenger version.



A cutaway drawing of the Tu-144MR, showing the main reconnaissance sensor array in the nose.

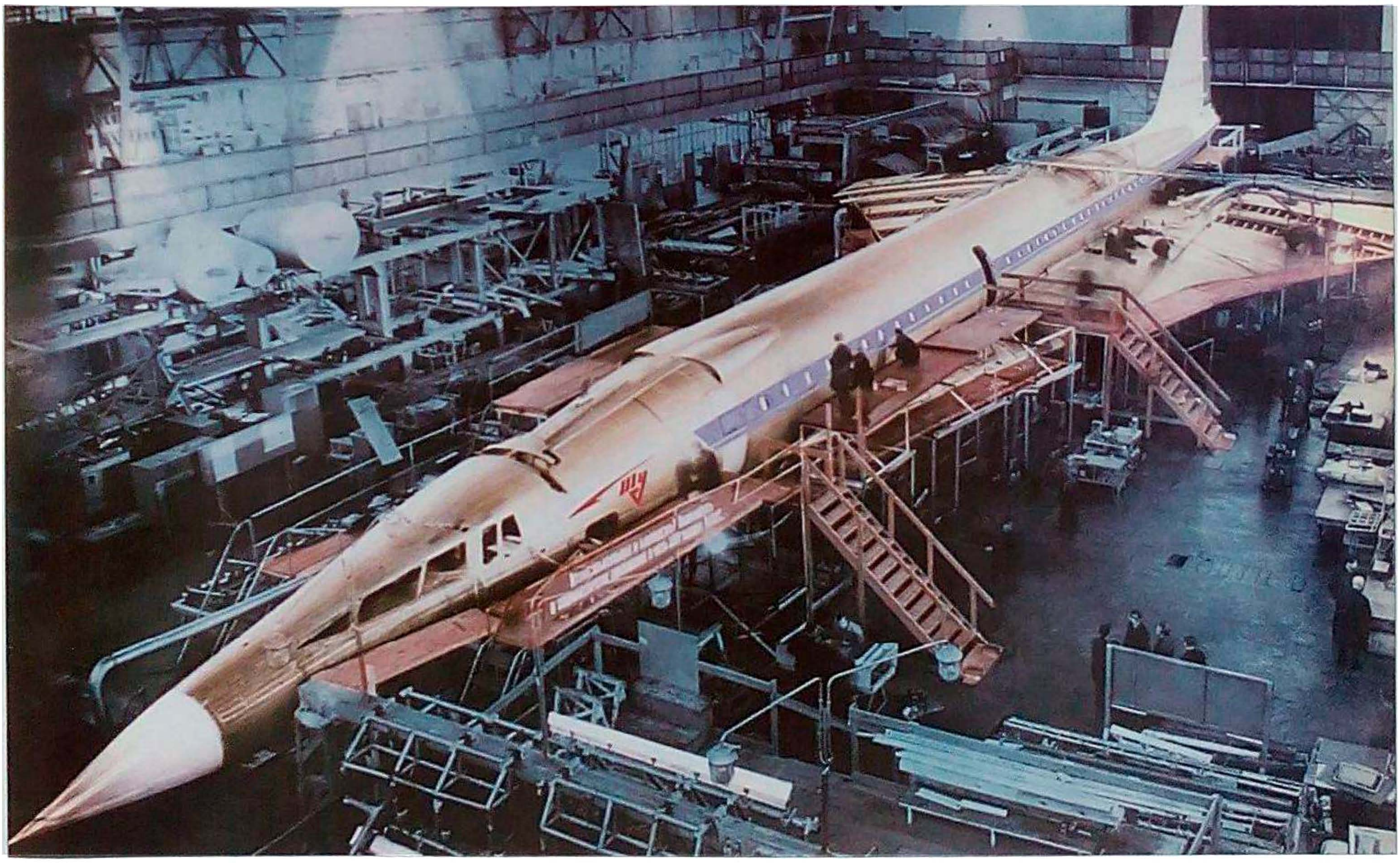
A three-view of the production Tu-144 *sans suffixe* (*izdeliye* 004).





A three-view of one of the Tu-244's project versions.

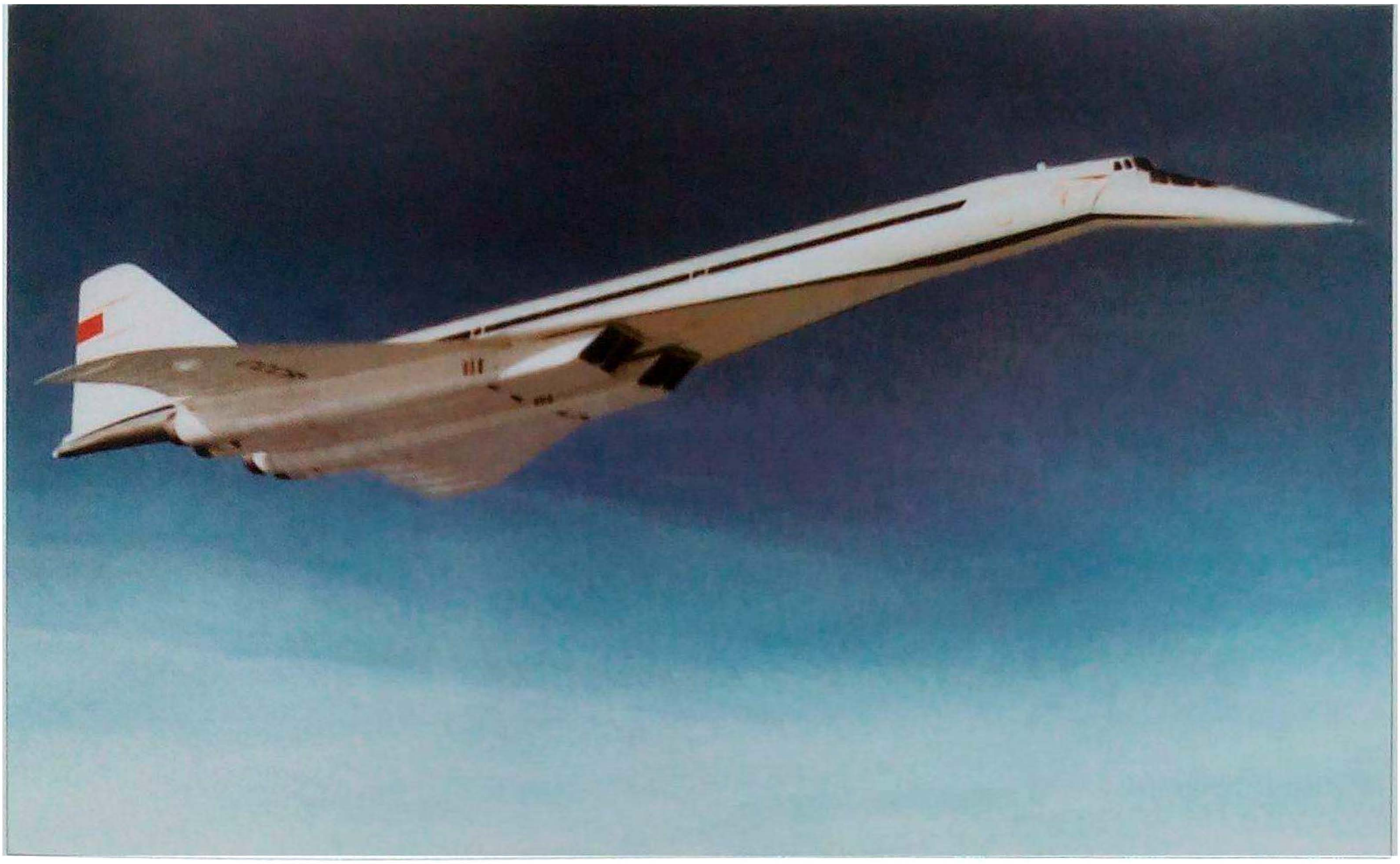
Above: CCCP-68001, the Tu-144 prototype, in flight with the MiG-21I flying chase.



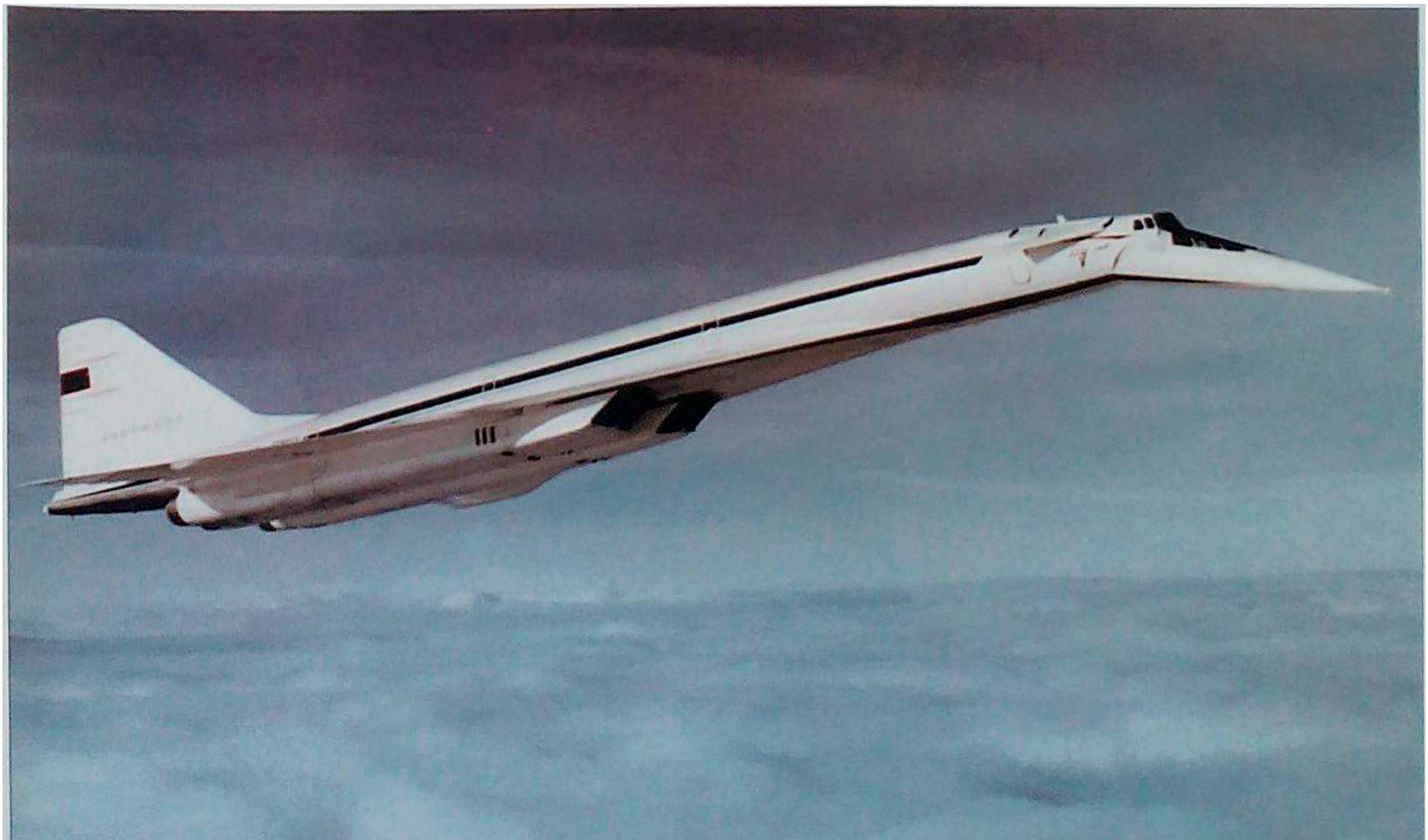
A production Tu-144 nearing completion. Interestingly, the blue cheatline and the red nose titles have been applied to a still basically unpainted fuselage!

Above: A production Tu-144 in the original version of the livery. Note the red-outlined doors.

A Tu-144 'burns rubber' at the moment of touchdown.



Above: A famous picture of a famous aircraft. CCCP-77101 is seen here with the nose lowered and the canards retracted.



The same aircraft a few minutes later as the canards begin to deploy.

With its nose perkily up in the air, the Tu-144 was a smart-looking aircraft. Note how the wing leading edge is painted blue, the colour extending forward almost all the way to the radome.

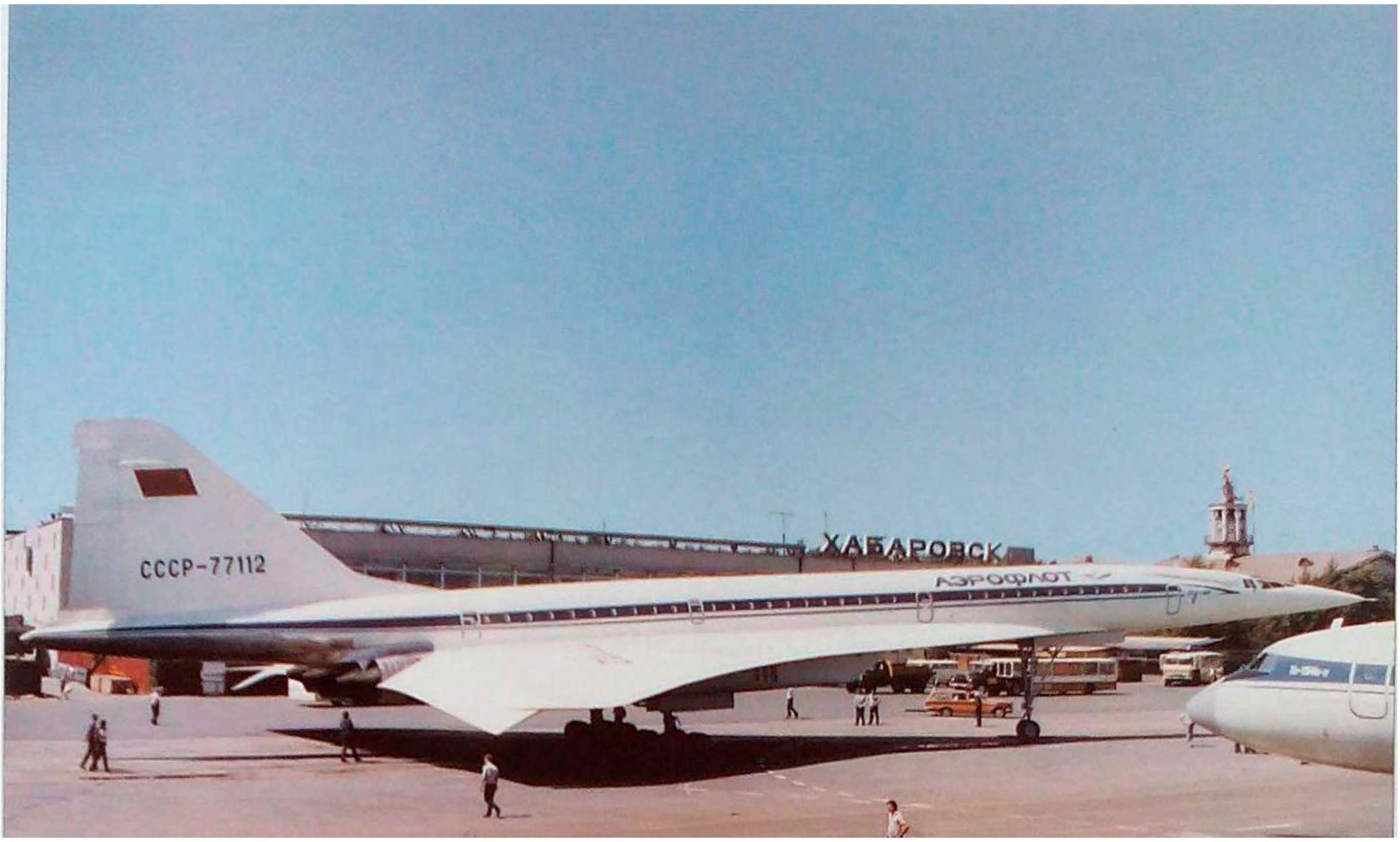
Another touchdown. This aspect illustrates well the extreme anhedral of the canards.

Above: Tu-144D CCCP-77112 taxying at Voronezh-Pridacha, the factory airfield. This aircraft was eventually sold to a German museum.

CCCP-77112 is serviced before a flight, with two TZ-22 fuel bowsers, which are KrAZ-258B 6x4 tractor units with 22,000-litre (4,840 Imp gal) semitrailers, pumping fuel and a UPG-300 providing ground power. The stair of the SPT-104 could barely reach the Tu-144's forward entry door.

Above: CCCP-77112 caught by the camera as the brake parachutes pop out and begin to deploy.

Glory days no more. Three Tu-144Ds languishing at the Tupolev OKB's flight test facility in Zhukovskiy in the 1990s. CCCP-77114, -77112 and -77113 had quite different fates (converted for research purposes, preserved and scrapped respectively).



Above: Tu-144D CCCP-77112 shares the apron at Khabarovsk-Novyy airport with an Aeroflot Tu-154B-2.

Another view of CCCP-77112 at Khabarovsk-Novyy in company with the Il'yushin IL-62Ms and Tu-154B-2s of the resident Far East CAD/1st Khabarovsk UAD.

Above: Still wearing its spurious '101' nose titles, the record-breaking Tu-114D CCCP-77114 is seen in the static park of the MAKS-93 airshow (31st August to 5th September 1993) at Zhukovskiy.

Another view of the '101' at the MAKS-93. The aircraft in the foreground is a full-scale mock-up of the projected VSKhS agricultural aircraft developed by the Tupolev OKB branch at the same Voronezh factory that built the Tu-144; it was later designated Tu-54.

Above: Tu-144D CCCP-77115 sitting some way apart from the other Tu-144s at Zhukovskiy, with Tu-204 CCCP-64004 (equally unflyable) to keep it company.

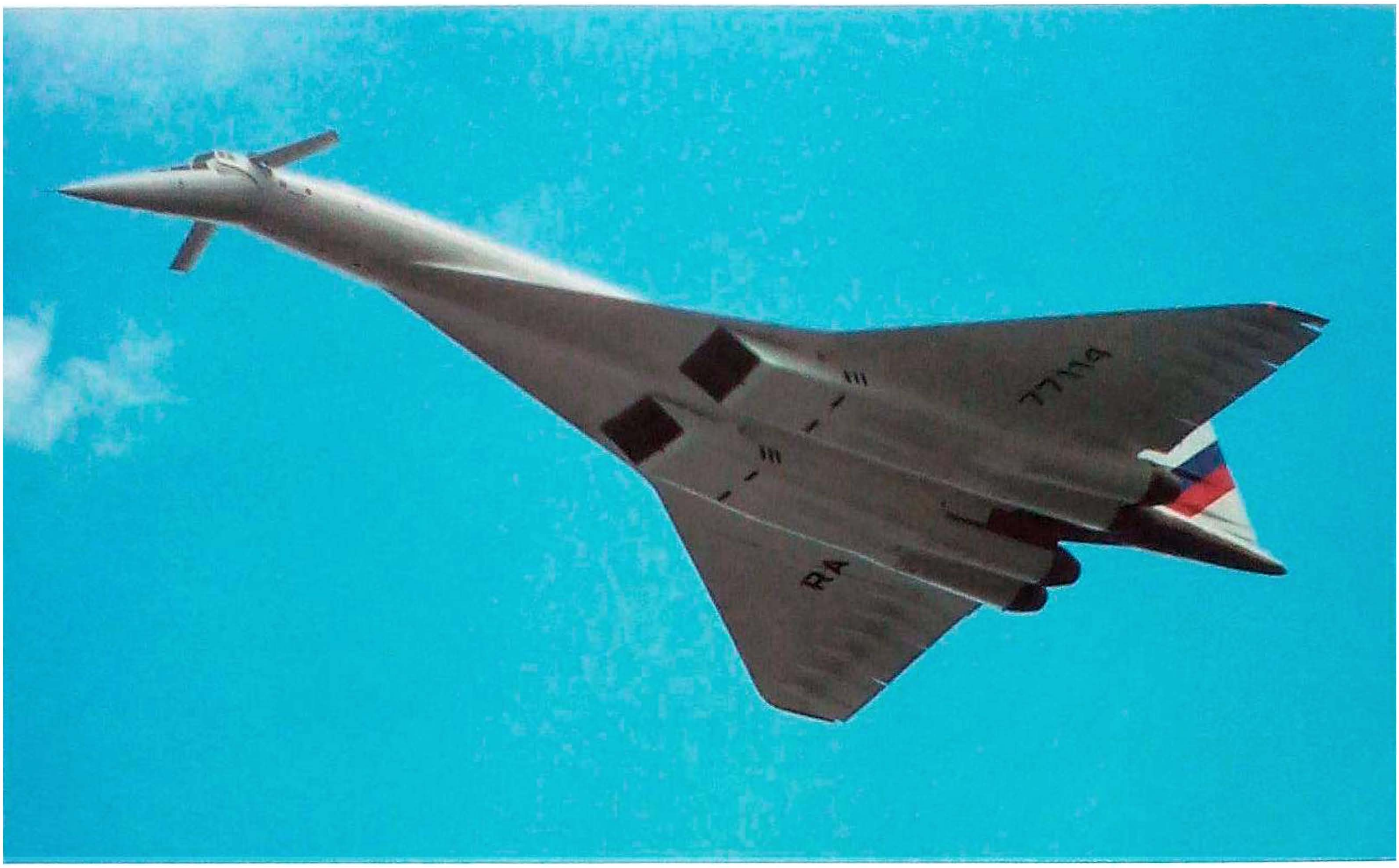
Another aspect of CCCP-77115, showing the characteristic nozzles of the RD36-51A engines.

One more angle on Tu-144D CCCP-77115. The very weathered finish after years of open storage is noteworthy.

RA-77114, the Tu-144LL research aircraft, received the finishing touches to its colour scheme in the hangar at Zhukovskiy.

Above: The Tu-144LL takes off on a test mission. Note the orange efflux of the NK-321 engines coloured by nitrous monoxide.

RA-77114 caught by the camera a second before it leaves the ground.

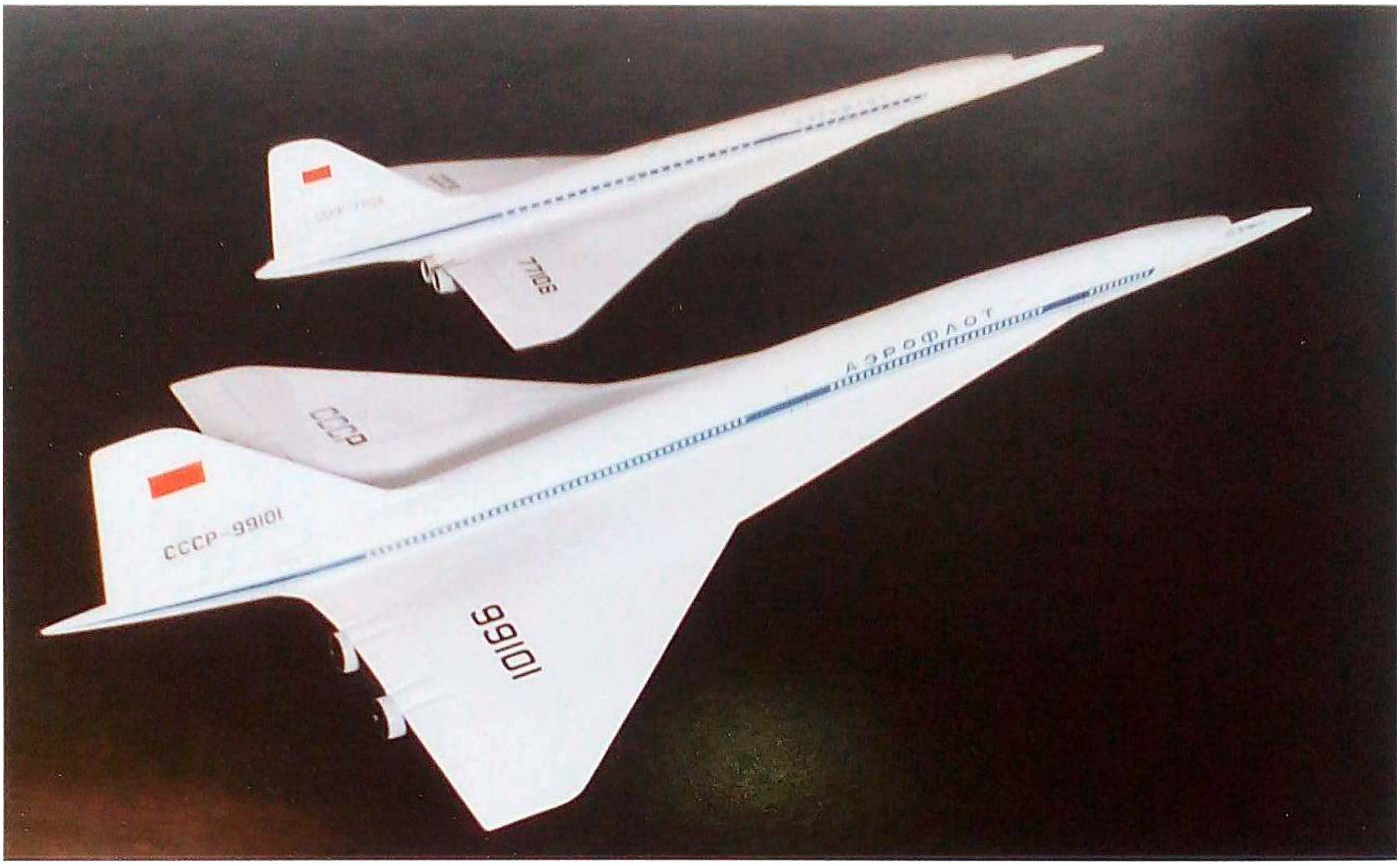


Above: The Tu-144LL makes a slow flypast with the canards deployed. Note the auxiliary blow-in doors on the engine nacelles.

RA-77114 on short finals to runway 30 at Zhukovskiy.

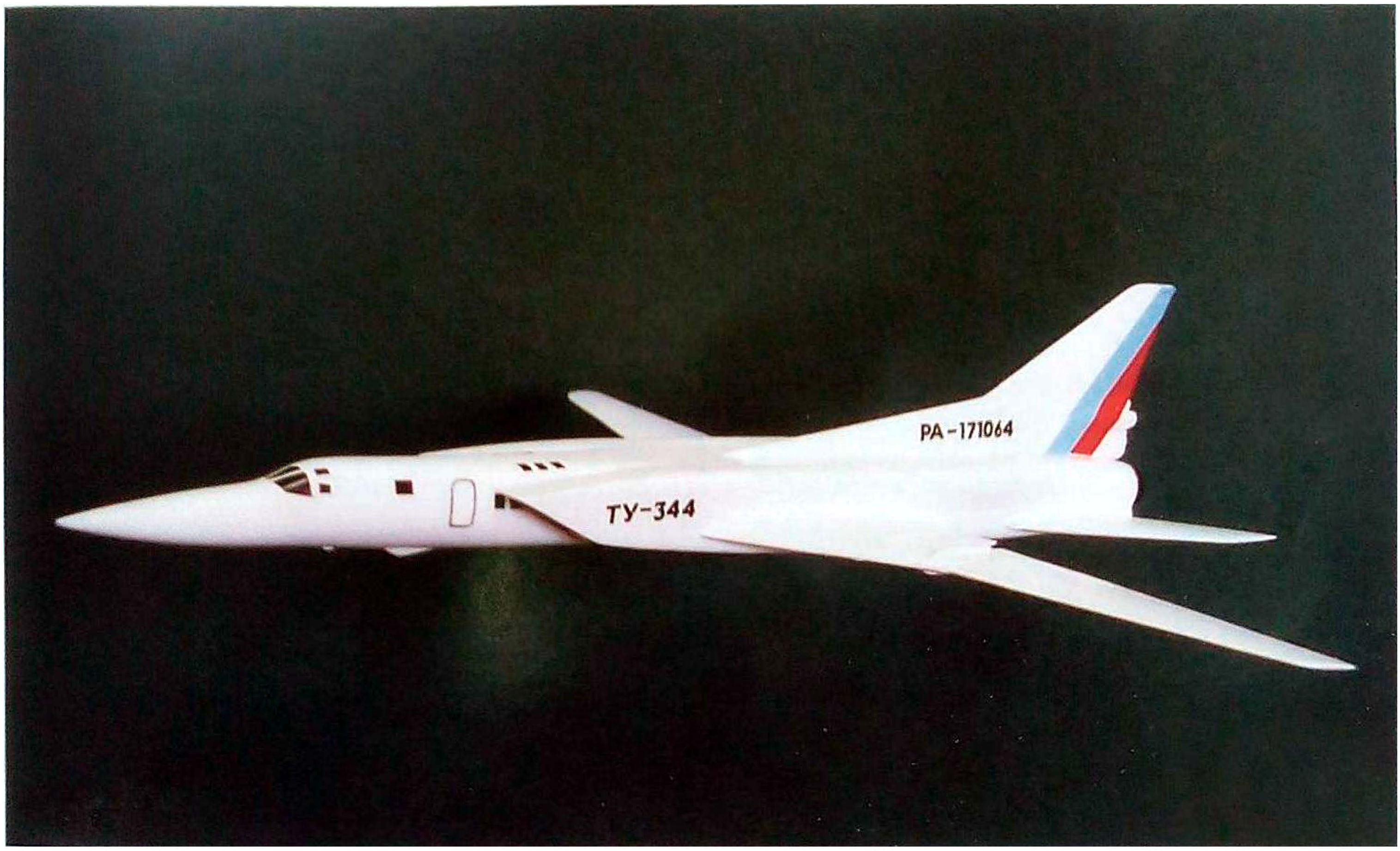
Above: The Tu-144LL sits in storage at Zhukovskiy after the end of the SST-2 research programme.

Another view of RA-77114, showing the dirty streaks running from the cabin windows – a 'feature' often seen on stored Russian airliners.



Above: These models graphically illustrate both the similarity and the difference between the Tu-144 and the Tu-244 as originally envisaged.

An artist's impression of the Tu-244 in its latest form.



Above: A model of the projected Tu-344 supersonic business jet.

The Tu-444 will be a far more elegant aircraft... if it materialises.

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Red Star Volume 17
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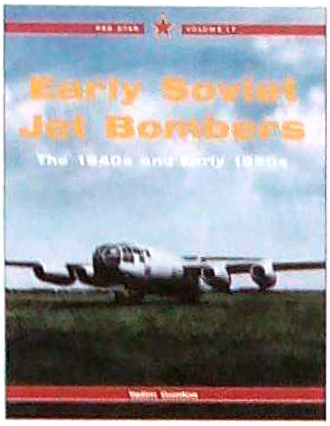
The 1940s and Early 1950s

Yefim Gordon



The Soviet Union put German technology to good use when developing its own jet bombers. The first to fly in the USSR was the Junkers EF131. This was followed by the EF140 and the equally unusual T-tailed, Baade 'aircraft 150'. The first wholly indigenous jet bomber was the four-engined IL-22 of 1947. Other experimental Ilyushins – the IL-30, IL-46 and IL-54 are described, as are the Tupolev 'aircraft 77', 'aircraft 82' and the 'aircraft 72/73/78' series.

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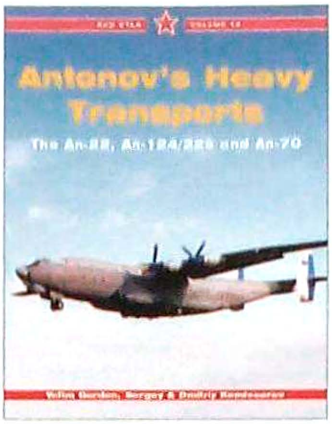

In recent times the Antonov design bureau has created a number of heavy transport types. In this volume the An-22 four turboprop aircraft is examined in detail as is the An-124, the Soviet answer to the C-5 Galaxy. Originally designed as a military freighter the An-124 has also found a niche in the civil market, as has its outsize six-engined development the An-225. The book is completed by a history and description of the propfan driven An-70 tactical transport, which is under development.

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Red Star Volume 19
SOVIET HEAVY INTERCEPTORS

Yefim Gordon

In the nervous 1950s, the Soviet Union faced the task of defending its borders against intrusions by Western spyplanes or bomber attacks. Aircraft developed for this priority long-range interception task included Mikoyan's I-3, I-7U, I-75 and Ye-152 which paved the way for the MiG-25, Sukhoi's T-37, terminated before it had a chance to fly, and Tupolev's Tu-128 – so huge it was mistaken for a medium bomber in the West.

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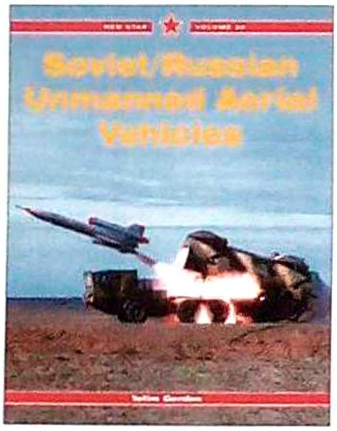

The Lavochkin OKB's La-17, produced in target drone and recce versions, was the first Soviet UAV to find large-scale use. The Tupolev OKB also developed a line of UAVs, including the Tu-123 Yastreb, Tu-141 Strizh, Tu-243 Reys and the latest Tu-300 recce/strike UAV. Yakovlev's unmanned aircraft are also covered including the Pchela (Bee) surveillance UAV. Mention is also made of UAVs and drones developed by such companies as Strela and the Moscow Aviation Institute.

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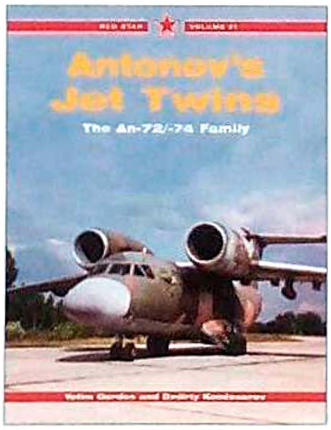
Yefim Gordon and Dmitriy Komissarov



The need to provide a state-of-the-art jet successor to the An-26 led Antonov to develop a twin-turbofan tactical airlifter, the An-72, with its signature high-mounted engines, employing the Coanda effect to dramatically improve wing lift and STOL capability.

The prototype flew in 1977 but it was not until the mid-1980s that production began. Comprehensive listings, both of An-72s and An-74s, detail registration/ Bort number, c/n, f/n and operator.

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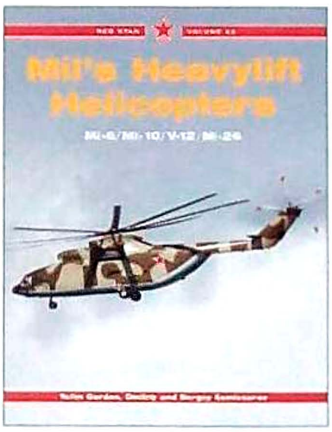

The prototype Mil' Mi-6 heavy transport and assault helicopter first flew in 1957. In 1959 it served as the basis for the unconventional Mi-10. In 1967, Mil' amazed the world with the mighty V-12 capable of lifting a 25-ton payload; then in 1977 the OKB achieved success with the smaller but more advanced Mi-26, the world's largest production helicopter. The development history, design and civil and military use of all three types is described in detail.

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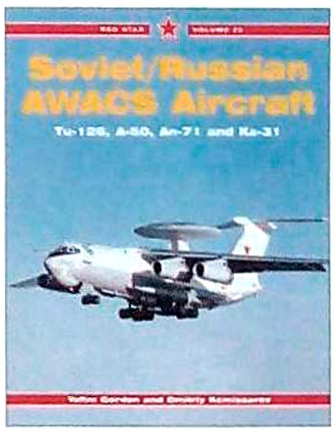

The need for effective protection of Soviet airspace in areas lacking adequate cover by ground radars led to work on airborne early warning systems. The Tu-126 AEW aircraft, evolved from the Tu-114 airliner, entered service in 1961. It was replaced in the early 1980s by the Ilyushin/Beriyev A-50 AWACS based on the IL-76MD. The highly unorthodox An-71 with its tail-mounted rotodome and the Ka-31 AEW helicopter are also described plus other unbuilt projects.

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